THE BOOK WAS DRENCHED

UNSOLVED PROBLEMS OF SCIENCE

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by

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AUTHOR'S NOTE

THE idea of this book came from a series of four short articles published under the same title in the *Morning Post*. These articles suggested, by their very brevity, that a book might usefully be devoted to a discussion of those aspects of scientific inquiry in which major problems still await solution. The book was to be popular, yet accurate; stimulating to the layman, yet not without value to the scientist; emphasising the unknown, yet providing, incidentally, a reliable picture of what was already known. It was neither to attack science for its partial failures, nor to stress unduly the many successes which have been achieved in recent years. It was, in short, to be a paragon of a book, such as has not yet been written and such as no one man could ever hope to write.

In such a case it may be pleaded that the aim, rather than the achievement, should be regarded as the justification. It is not only laymen who are bewildered by the sweep of scientific progress. Outside his own immediate field of work the scientist himself is scarcely in better case. He has little time for what does not directly concern him; and even within his own subject is in continual danger of submersion by the ever-growing flood of papers, periodicals and reports, written in many languages besides his own. There is therefore a real need for a wider literature, even if something of accuracy and completeness is lost in its production. As a disarming Chinese proverb has it:

> "It is better to be a crystal and to be broken,
> Than to remain perfect like a tile upon the housetop."

As an example of another type of difficulty, I may add that during the brief interval since chapter six (*Messages from Space*) was written, another and possibly important link has been added to an argument therein contained. The evidence of sounding balloons, meteors and the long distance travel of sound waves, it is explained in the text, all combines to show that high up in the earth's atmosphere there is a marked rise in temperature. Now a fourth line of evidence has been added. Professor E. V. Appleton of King's College, London, has deduced from radio records that the temperature at the upper of the two wireless-reflecting layers, about 150 miles above the earth, must rise to about 1300 degrees Fahrenheit during a summer noon. This announcement in no way conflicts with any previous judgement. The exploration of the upper atmosphere has merely been carried one step farther. It is not without interest that four such widely different lines of approach should lead to similar conclusions.

For this particular omission from the text there is a valid excuse. Covering so wide a field, and with so ambitious a programme, I am afraid that both errors and omissions must be accepted as inevitable. For the removal of a number of faults of both kinds I am indebted to many friends who have helped either by reading portions of the manuscript or in other ways. No doubt there are others for which the responsibility can only be mine. "E. and O.E."—these are the only terms on which a book of this character can reasonably be offered.

As regards authorities, I have consulted original papers wherever practicable, particularly when dealing with

recent work. In two cases, however, standard reference-books are available which are very nearly, though not quite, up-to-date. I refer to Sir Arthur Keith's *Antiquity of Man*, as modified by his *New Discoveries relating to the Antiquity of Man*, and to Professor V. E. Gordon Childe's *New Light on the Most Ancient East*. Each, with the addition of such further material as seemed necessary, has been used to provide the foundation of a chapter, for which I here make inadequate acknowledgement. The writing of two other chapters (VI and XIII) has been enormously simplified by the full reports of the recent international conference on physics which have been published by the Physical Society. I am also indebted to the General Electric Company for technical information concerning the new gas discharge lamps, to which reference is made in the last chapter; and to Friedr. Vieweg and Sohn for the diagram from *The Origin of Continents and Oceans* by Alfred Wegener (Methuen.)

I should perhaps add that all temperatures are given on the Fahrenheit scale. Such a departure from normal scientific usage does not, I think, call for any apology in what is primarily intended as a popular work. Similarly I have used the term "weight" instead of "mass" on the ground that intelligibility is of more importance than strict precision of meaning.

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CHAPTER I

THE UNENDING QUEST

SCIENTISTS do not know (among other things) why sugar tastes sweet, why a steel girder is not a hundred or a thousand times stronger than it is, or why some summers are dry and others wet. They are equally ignorant of the nature of life, and of the cause of the common cold. Even if they knew the first, it by no means follows that the second and relatively commonplace problem would be immediately unravelled. Atoms and stars alike still guard many of their secrets. Rust and moth still levy their toll of waste. The ignorance of science is at least as diverse as its knowledge, and in many ways more interesting. Moreover, in an age which habitually despatches its letters by air and its music by the ether it is no bad thing to look, for a short space, at the reverse side of the picture. There are many more things to be learnt, both curious and important, than two or three generations of concentrated inquiry have yet disclosed.

The glow-worm still lights his lamp more economically than can man; the silk-worm's product is still inimitable by any textile factory; and no human engineer can convert the sun's energy into living food as every green plant does day by day. Not only can the scientist not make his own food (to any appreciable extent), but if

placed in the middle of the Sahara he would want a considerable supply of both raw materials and apparatus before he could manufacture sufficient water to keep himself alive. It is an old saying, beloved of educational advertisers, that knowledge is power. But the necessary knowledge to do any of these things has not yet been won.

To admit the extent of man's ignorance should not be depressing. It is not so very long, on the cosmic time scale, since Isaac Newton admitted that he felt like a child throwing pebbles into an illimitable ocean, to which he could approach no nearer than the edge. Since Newton's day the ocean of ignorance has been driven back more than a little. The science of chemistry has been born and, from a feeble infant has grown up to beget a mighty industry. The nature of light has been unravelled, and led in turn to new knowledge of X-rays and radio. If the steam engine has revolutionised industry, the petrol engine has conquered the air. The air itself has yielded unsuspected gases, used in the ordinary domestic lamp and in those coloured advertising signs which illumine every great city at night. Nitrogen, also from the air, has been transformed into artificial fertilisers to increase man's food supply, and science has discovered how to carry food from one end of the earth to the other in perfect condition. At the same time man's death rate has been reduced by about half. A host of diseases from malaria to diabetes have been either conquered or held at arm's length. Other causes of ill health would be as certainly removed if society would

but apply to its proper purpose the increased agricultural capacity which science has given it.

Even with the discoveries already made science could do many times more than it has already done to promote the wealth and happiness of the world. No one seriously doubts that a relatively small number of hours work a day would be sufficient to maintain every man, woman and child in the world in a vastly higher standard of comfort, housing and health than has yet been realised. The difficulties are difficulties of organisation rather than of knowledge, and the scientist cannot be held responsible, although he is beginning to realise that his work is being inadequately applied. The only serious attempt at that application is being made in Russia to-day. Only an optimist could say that the experiment was yet succeeding; and only a super-optimist could argue that the diverse productive output of a highly industrialised country could be successfully controlled and co-ordinated in any cut-and-dried plan. The problem is to combine the effects of intelligent planning with the flexibility of so-called capitalist organisation; and then to provide still greater flexibility, so that new inventions shall no longer be stifled or held up by vested interests, as is too often the case to-day. Organising and inventive ability must have its reward, yet there must be no exploitation. It is a titanic task, the greatest which the world has yet faced. Common sense suggests that such complex problems will be solved by no one formula, however attractive. But no one can doubt that in the long run, if not in

the lifetime of the present generation, they will be solved.

If the achievements and the promise of science have been emphasised rather in terms of industry than of pure knowledge, this is because it is through industry and the social life of industrialised countries that the power of science is most obviously manifest. Sufficient has at any rate been said to indicate that, judged by any standards whatever, science has done well. There is, however, one other criticism which it may be well to demolish at the start. It is represented by the word "revolution". Scientific theory or knowledge, we are told month by month, almost week by week, in popular articles, has been revolutionised by some new discovery. The truth is very much more prosaic. Scientific discoveries are seldom wholly new, and scientific theories are seldom revolutionised. In the field of discovery, one man's work builds, often imperceptibly, on that of many others. If laymen ever read scientific journals, with their innumerable references to previous work, they would be in no doubt on that point. Nor is the progress of scientific theory destructive. Old theories are not as a rule demolished. They are merely extended to explain a wider range of facts.

In recent years, for example, it has been discovered that light behaves in many ways as if it consisted of particles. It seems that in its most fundamental aspects the new theory of light must be considered as a particle theory. But light behaves, as it has always done, as waves; and, whatever happens, the wave theory of light

can never be superseded. So also with Newton and Einstein. Newton's law of gravitation still holds good. But from a universal truth it has changed to an approximation good enough for nearly all practical purposes. Within the small world of the atom and, to a lesser extent, in the large world of astronomy, it has proved to be insufficiently accurate. Newton has, so to speak, been incorporated in Einstein. But the facts on which Newton's law was based are still as true to-day as two hundred and fifty years ago. Time was when the king's death meant that the king's law ceased to run. The proud phrase, "The King is dead. Long live the King", is as necessary in scientific as it ever was in political theory.

So much may be truly said, yet the fact remains that the ignorance of science is not merely interesting, but is significant also. It is an obvious paradox that the more science knows, the more there is to find out. Until the great distances of the stars had been discovered, there could be no knowledge of their nature. Until the nature of the stars was to some extent known, there could be no speculation as to their origin. It is so in every branch of discovery. The ignorance of one generation is the knowledge of the next. The mere fact that a problem is to-day classed as unsolved implies that the problem, if not the solution, has been discovered. It follows that when the means are available an attempt will be made to solve it—and, in all probability, still other problems will be raised in the process.

From another point of view, the area of ignorance is

largely determined by the material equipment available. Knowledge of the structure of solids had, in the main, to wait for the discovery of X-rays. The knowledge of astronomers has been in part dependent on improvement in telescopic technique, in part also on the development of more sensitive photographic plates. Plasticine, which we normally think of as a modelling material, was at one stage of very real importance in the exploration of the atom. Would-be atom-splitters have to maintain high vacua in their apparatus. They also, particularly in the early days, had to make frequent alterations and adjustments. Plasticine filled the gap. In still another field, the detailed study of nerve impulses within the human body was even more directly the child of radio. A high degree of amplification is necessary for the measurement of the minute electrical currents involved.

In some cases new lines of future progress can be immediately foreseen. The intensive study of metal alloys, primarily undertaken for other purposes, is likely to lead to the substitution of metal for glass in the construction of large telescope mirrors, with a corresponding reduction in weight and a further possible increase in size. In the case of atom-splitting, two factors are operating to increase the electrical voltages at the disposal of scientists. One is the need of electrical industry for more effective high voltage insulators, and more particularly for detailed knowledge of the effects of "lightning surges" in transmission systems; the other is the belief that a 2,000,000 volt X-ray tube will provide the medical equivalent of radium. The stimulus is, in

both cases, industrial. The result, unquestionably, will be new knowledge of the atom which in turn may produce further repercussions in industry. And so the perpetual interplay of science and industry goes on.

The ignorance of science is very far from being merely static. It is also of many different kinds. There is ignorance temporary, as of a man who does not know which omnibus to take to get from one part of a town to another. Such is the ignorance of science in the making of metallic alloys for particular purposes. The problem of how to make metal mirrors for giant telescopes has already been mentioned. The requirements of astronomers in this connection have lately been formulated by the Astronomer Royal. He asked chemists to produce an alloy that (among other properties) should be light, expand little with changing temperature, be absolutely rigid and keep its shape well. It is probable that chemists will one day discover what metals should be mixed together in what proportions, and in what way, to produce the kind of alloy the Astronomer Royal wants. Such an alloy would lead to cheaper giant telescopes (the one now under construction at Mount Wilson is likely to cost a matter of two million pounds). It would also lead to a number of new astronomical discoveries, perhaps even to a new picture of the outer universe which it is the primary business of large telescopes to explore. But for the making of the alloy itself it is unlikely that new knowledge of any general kind would be required. The ignorance which has prevented it being produced is merely cookery book ignorance, rein-

forced by a lack of appreciation on the part of the metal industry of what astronomers wanted. That is not a very satisfactory sort of ignorance to talk about. It amounts to the rather uninteresting statement that if a sufficient number of people took a sufficient amount of trouble, the problem would be solved.

There are also, returning to the analogy of the omnibus, two other kinds of ignorance which in practice are very closely related. There is the ignorance of the man who merely sees an omnibus and has no idea where it is going; and there is the ignorance of the man who knows where a number of different buses are going, but has not yet discovered how the different services are connected or why their time schedules are arranged as they are. The two types of ignorance are very obviously connected.

It would clearly be of no avail for a student of city transport to attempt to probe its rationale unless he had first acquainted himself with at least the main features of its working. Our transport student would therefore decide to collect the facts first and interpret them afterwards. Human beings are, however, both inquisitive and lazy. And so, long before he had collected all the facts, he would begin to speculate. He would so far yield to his curiosity as to put forward what he would grandiloquently describe as a series of working hypotheses. He might, for example, notice at any early stage in his inquiry that extra facilities were provided on certain routes between the hours of, say, eight and ten in the morning and five and seven in the evening.

He would then put forward as a hypothesis the theory that these represented two "rush periods". This he would have to test. Finally he might proceed to draw a number of further conclusions as to the habits of city dwellers which, though apparently unconnected with omnibus services, yet seemed to follow with equal certainty from the theory put forward. Naturally he would proceed to verify these facts also, and the more predictions which he succeeded in verifying the more confident would he feel of the truth of his theory.

Most of the unsolved problems of science which can be usefully discussed fall into this mixed category. A few facts are collected and a provisional hypothesis put forward to explain them. Some of the "facts" will be established with certainty. Others will still be subject to doubt, sometimes in respect of the observations themselves, more often as regards their interpretation. At the same time the facts may be explicable in terms of more than one theory; or some part of the facts may be provisionally explained in terms of one theory and the rest in terms of some other theory. The obvious conclusion in this case is that there is a certain amount of truth in both theories, but that they have not yet been correctly fitted together.

If we change our analogy, for a moment, from omnibus to railway transport we can get some sort of picture of how this may come about. We know, as it happens, that rail speeds are governed in part by the congestion of the track, as represented by the signal system, and in

part by the power of the engine and the load behind it. But let us suppose for the moment that we are ignorant of both these factors. An observer, concentrating solely on the signal system, might notice that in a busy area the engines always accelerated when a green signal was showing and always reduced speed in face of a red light. But having no knowledge of engines, he might miss altogether the equally important fact that each locomotive had a limiting speed, dependent partly on the power it could generate, and partly also on the load it was pulling and the gradient it was facing. On the other hand an observer who had never seen a railway track before might fail to notice the signal system, while obtaining full data as to the pulling power of different engines. Each observer would be compelled to agree that the other had made an important contribution to the advance of knowledge, and they would agree also in the pious hope that one day their two points of view would be reconciled. To us, who know all about it, the whole affair would appear fantastic. But we cannot really afford to scoff, for the position in many branches of scientific inquiry is exactly analogous.

Take for example "The Creation of the Universe", which rather naturally occupies the first position on our list of unsolved problems. The creation, in any full sense, implies the appearance of matter as we now know it, the birth of planetary systems from stars, the birth of the stars themselves, the birth of the different universes of which the stars are members, and finally the beginning of a process of expansion which is every year carrying

the different universes farther away from one another. Each line of approach must have something to tell us of the main problem. Yet, as we shall see, we can only guess that all these different processes are connected; and for the time being rely mainly on one of them, the expansion process, for our picture of the beginning of things.

Two other problems, "Nature's Building Bricks" and "Mathematics or Common Sense?", represent two entirely different pictures of the atom which science has only lately begun to reconcile. From one point of view the atom is built up of a limited number of kinds of particle, "Nature's Building Bricks". Yet in other aspects we are now told that these particles are quite unlike any normal building units that we can imagine; that they may not even be amenable to the law of cause and effect, so that although we might have full knowledge of all the circumstances it by no means follows that we could safely prophesy what any individual particle might be doing a second or a minute or a year hence. Worse still, it is not even clear that we shall ever be able to tell with certainty how any individual particle is behaving now. Here certainly is a strange *Alice in Wonderland* picture of the nature of matter which must have far reaching consequences in the realm of ideas. If it sounds more than a little abstract, we may remember that matter is the stuff that we ourselves are made of as well as all our belongings.

So we might run through the list and notice that almost all of the major problems of science involve a

many-sided approach. The next, "Is Man a Machine?", is from one point of view a straightforward, if as yet unanswered, question of heredity and human behaviour. Yet it involves the nature of life itself, which in turn implies at least a passing survey of many different lines of evidence. It is so also with "The Beginnings of Civilisation" which we can either approach scientifically (in the ordinary sense) through a discussion of the probable origin of cultivated grain, or archaeologically through the known remains of early man. But catalogues tend to become dull, and I will content myself with pointing out that we shall find throughout that science is advancing through a mixture of fact and theory. A limited number of facts suggest a tentative theory. But the theory is only half baked. New facts may either complete the baking, or change the recipe beyond recognition in the middle of the cookery process. At the same time a scientific cake differs from any ordinary cake in that, even in the middle of cooking, the progress of the cake suggests new ingredients for which a place should be found. If the new ingredients will not mix, then the recipe may have to be changed. Another difference from any ordinary cookery is that the cakes which science is baking are all ultimately destined to be re-cooked in a single composite pudding. Ultimately the whole of science will be one. The composite pudding is already, so the master cooks report, progressing as satisfactorily as can be expected; and we need not be unduly perturbed if some of the outlying cakes continue to give anxiety. They can always be

re-baked, and the main texture of the pudding will not be affected.

Finally there is one other kind of ignorance for which science cannot rightly be blamed, for it is of the very essence of the scientific method. The purpose of science is to analyse, to explain and to control. But it is impossible to explain anything unless we have something else in terms of which to explain it; and so, in the last resort there must always remain something which can neither be explained nor analysed. The chemist, for example, can tell us that a chemical is built up of such-and-such kinds of atom in such-and-such proportions. The crystallographer, with the aid of X-rays, can tell us how these different atoms are arranged. The atom-splitter can tell us (or will one day be able to tell us) the exact way in which each kind of atom is itself built up of positive and negative electricity, of protons and electrons. But if we ask him what protons and electrons are, he can only take a sheet of paper and write down a series of equations which represent, so he will tell us, the way in which protons and electrons behave. He has carried analysis, so far as we can tell, to the ultimate limit, and so he has nothing else in terms of which to explain them. He has to take refuge in mathematical symbols, and it is not easy to believe that a mathematical symbol can represent the nature of anything.

We meet the same kind of difficulty in regard to radiation. We can say that radio waves are like light waves, but of longer wave-length. Or we can say that light waves are like radio waves, but of shorter wave-

length. But if we ask what radio and light waves are, the scientist has again to take refuge in mathematics, which is only another way of admitting that he has already gone as far as he can. His equations will tell us how the different kinds of waves are related and how each will behave. But nothing more.

These particular limits may not be final. The ultimate units of matter, as we now know them, may be explained in terms of something more fundamental. But the general conclusion is logically inescapable. Sooner or later, science must come up against the ultimate warning sign, "Thus far, and no farther". What is the meaning of this limitation? It is that in the last analysis science can only tell us how things behave, not what they are An immediate corollary is that science has a great deal less to tell the world about religion than is generally supposed.

Sir Arthur Eddington has lately rebuked Sir James Jeans for suggesting that "the Great Architect of the Universe now begins to appear as a pure mathematician". The fact that the modern scientific picture is of its nature mathematical, Sir Arthur points out, carries no such implication; and when he himself proceeds to discuss the validity of religious experience he frankly bases his conclusions on his own consciousness. It is curious that he should have been criticised in many quarters for so doing. Perhaps the real criticism is that Sir Arthur has in effect used his eminence as a scientist to propagate his views in quite a different sphere. But that is hardly fair. Sir Arthur has at least as much right

to his opinions as anyone else, and has rather more right to suppose that they will be regarded as of interest.

The fact, however, remains that such discussions are outside the scope of science. The contemplation of the universe may predispose to an idealistic philosophy. But the contributions of science to religion are essentially of a negative character, and the real conflict has been between science and dogmatic theology. Evolution, for example, has told theologians that the account of the Creation, as given in the first chapter of Genesis, is not literally correct. The world has therefore had to abandon the first chapter of Genesis as a source of scientific enlightenment. But except for the Fundamentalist, who believes that every word in the Bible is literally true, no change is involved of any importance. It is quite possible, from evolution, to draw the conclusion that man is no more than a glorified animal. It is also possible to believe, as the Catholic Church permits, that at a certain stage in his evolution man was given a soul. Nor can the possibility be denied that every living creature may be, in some sort, the possessor of a soul. Between these three possibilities science, as such, has no guidance to offer. It merely appears to particular individuals that some one belief is more plausible than the others.

At the present time a new impact of science on theology appears imminent. Science, as has already been mentioned, has lately discovered that the reign of cause and effect may be by no means universal. The behaviour of the physical universe, it is beginning to appear, may have

to be regarded as unpredictable, even by its Creator. This is a conception of which theologians as well as philosophers will have to take account. It will also, if finally established, be the supreme example of the ignorance of science. But it does not follow that this new ignorance will have any more serious repercussions on religion than has scientific knowledge in the shape of evolution.

CHAPTER II

THE CREATION OF THE UNIVERSE

"IN the beginning God created the heaven and the earth." There is nothing more difficult to imagine than the creation, in the sense in which it is normally understood. It is not so much a matter of the violation of scientific law, which after all is outside the purview of most of us, but of the inherent inconceivableness of the sudden appearance of matter and energy out of nothing. We may be able to imagine that St Paul's Cathedral might one day be lifted, without apparent reason, into the air; that water should be turned into wine; or that man should walk upon the face of the waters. In each case scientific laws, as we know them, would be violated. But no one of these things is so difficult to imagine as the greater miracle of creation, as this is normally conceived.

Can modern science offer any help? Can it provide a picture of the beginning of the universe, which is free from this inherent difficulty of the creation of matter as such? Atomic science, with all its triumphs, gives little help. It teaches us that matter and radiant energy are interchangeable. But that takes us little farther. Whereas it was formerly believed that the sum totals of matter and energy in the universe were immutable and constant, the barrier between the two has merely been broken. Matter has become a form of energy; but energy, in-

cluding matter, remains uncreatable and indestructible. It is simpler to believe that matter and energy were, and always will be, and that the creative process, if there was one, was of a different kind.

For an alternative picture we may turn to astronomy, the one science which probes the universe in the larger sense; and, while we shall find that more than one picture is possible and that any picture involves an element of speculation, we may also hope to find that the venture is worth while. If the creation of the universe is always likely to remain an unsolved problem, from the point of view of a scientist, it is at least a problem on which ideas are beginning to crystallise.

We may begin by noticing the change of proportion which has been effected by the discoveries of astronomers, with a certain amount of aid from Charles Darwin. The earth, with its mountains and seas, its myriad beauties of colour and form, its countless varieties of living creatures, its monkeys and its men, no longer represents the main problem of creation. Time was when it was taken for granted that the earth was the centre of the universe, and man the self-appointed lord of creation. Aristarchus of Samos had indeed impertinently suggested more than twenty-two hundred years ago that the sun, and not the earth, was the centre of the universe. But not for eighteen hundred years did he find a supporter apart from his immediate followers; and even then it was not at once realised that men lived a matter of 93 million miles away from what then appeared to be the hub of things. As for the stars, they had not yet been rescued from the limbo

of philosophic wonderment, in which God could taunt his good servant Job with his inability to number the Pleiades.

The next step was the realisation that our sun, which seemed so large and hot, was but one of many. How rapid has been the expansion of the cosmic scale is shown by the fact that it was not until 1838, less than a hundred years ago, that the German astronomer, Bessel, made the first reliable measurement of the distance of a star. The star which he measured was, relatively speaking, a near neighbour of the sun. Yet it turned out, in round figures, to be roughly a million times as far away. Astronomers had taken their second important step in their outwards journey into space—and it is perhaps worth noticing that the distances of all the nearer stars can be measured with very fair accuracy with no further assumptions than are implied in the process of trigonometrical surveying on which all our maps are based. The limit of this direct system of measurement comes at about thirty times the distance of the star to which it was first applied. Beyond that limit, certain assumptions have to be made before any measurement, or perhaps it would be truer to say estimate, of distance can be given.

As the ideas of astronomers on the probable beginnings of the universe depend on their picture of the universe as it now is, it is well that we should have some idea of how this picture is arrived at. Broadly speaking the position is this. For what we call "near" distances the direct or surveying method is used. For "middle" distances a second method is used which has been proved to agree

with the first method in the case of "near distance" measurements, and is assumed to apply with equal accuracy up to the limit to which it can be used. This amounts to supposing that a particular type of star, which is known to behave in a certain way when it is near enough to be adequately observed, behaves in the same way when its behaviour can no longer be checked. Finally for "great distances" yet a third method is invoked. In each case the change-over involves some loss in accuracy. The greatest astronomical distances cannot therefore be regarded as more than approximate estimates, even supposing that the assumptions underlying these estimates are justified—as they probably are. When, therefore, we are told that such-and-such an object, just discerned in one of the world's highest powered telescopes, is 2 (followed by some fabulous number of noughts) miles away, we should understand that the number of noughts is likely to be correct, but that the 2 may mean anything between, say, 1·8 and 2·2.

It is amid these titanic figures that the clue to the creation lies. The first star to have its distance accurately measured was, it will be remembered, about a million times as far away as our own sun. If we expand this distance four-thousandfold we shall have a rough idea of the extent of our own sun's system of stars. It comprises not only the five thousand odd stars which we can see with the naked eye, but thousands of millions of stars which we cannot see, a very large number of which are included in the faintly luminous cloud of the Milky Way. Here, it might be thought, was an adequate field for specu-

lation. Explain how all these stars came into existence, why they are of different types and why they are arranged as they are, and the mystery of creation will have been solved. So, a generation or two ago, the problem must have appeared.

Nowadays the cosmic scale must be still further extended. Beyond and outside the countless millions of stars of which our sun is one, lie millions more of other universes, each containing, in all probability, their own quota of thousands of millions of stars. In what follows "universe" should be taken to apply to these separate universes, what an astronomer would call galaxies; and "Universe" to mean all the universes, that is everything that exists. The latter is, of course, the proper use of the word. But there is unfortunately no other expression which adequately conveys the immense size of these "island universes". Even the nearest of them only come within our scale of "middle distances", but in the most powerful telescopes many of their component stars can be separately observed and have been found to be of types already known in our system. There is good reason, therefore, to believe that they are not very different from our own system of stars, and there is good reason also to believe that they are of the same sort of size.

For the purposes of creation, these island universes must be, so to speak, our unit of speculation. It will therefore be convenient to make our ideas of how they are scattered in space rather more definite. We have now got to the stage when mere distances are meaningless. I will ask you therefore to imagine that all the thousands of

millions of stars of our own system are compressed into a penny. The comparison, it may be added, is to this extent apt in that both our own and other universes are supposed to be roughly disc-shaped. On that scale the nearest universe to our own is about two pennies width away, so that from the point of view of an outside observer we must appear as one member of a pair of twin universes. Similarly the most distant universe which has yet been measured is about six hundred pennies widths away, and this also is a member of a group of neighbouring universes.

It is indeed a characteristic of universes that they seem to run in groups, so that there are not only galaxies of stars but galaxies of galaxies. Within this range are thousands and thousands of other universes. The distant universes are therefore very much nearer neighbours, relatively speaking, than are the stars. Sir James Jeans has calculated that six wasps flying about in a cage the size of Europe would just about provide a scale model of a random sample from the star population of our own universe. If we made each wasp represent a universe instead of a star we should want an almost incalculable number of wasps to fill a cage that size.

If the observation of distant universes in the world's largest and most expensive telescopes led to no other result than the multiplication of records of the numbers and distances of universes, it might well be argued that little further profit was to be got from continuing the process any further. As soon, however, as astronomers began to make reliable estimates of the distances of other universes, they made a very surprising discovery. They

found that all the more distant universes showed their dislike of our own by running away from it as fast as they could. A few of our nearer neighbours appeared, it is true, to be moving towards instead of away from us. But this could be explained by relatively small random variations in their speed and direction of movement. At greater distance it was found that all the universes were moving away from our own, and that the speed of their departure was exactly proportional to their distances. If one universe is twice as far away as another, it is automatically found that it is running away from us twice as fast as the nearer one. The most distant universe yet observed is, to all appearances, running away at the almost incredible speed of 24,000 miles a second, rather more than one-eighth the speed of light.

Measurements of these speeds naturally involve some deductive process. We cannot stand, stop-watch in hand, and measure the speed of a universe. Even at their enormous speeds of movement an interval of half a million years would be needed to produce a 10 per cent. increase in distance, about the smallest which could be measured with any certainty. Astronomers' measurements are therefore indirect. But, although indirect, they are based on a recognised physical principle which has been found to be perfectly valid in other cases.

It is a well-known fact that the pitch of an engine's whistle drops appreciably as a train roars past an observer standing beside the line. This is because the length of the sound-waves is affected by the speed at which the engine is moving relative to the listener. There is no reason

why the same principle should not apply in the case of light-waves, and small changes in the wave-length of the various kinds of light emitted by stars have in fact been successfully used to measure their speed of movement. Moreover, there are many pairs of "twin" stars, which were first proved to be "twin" in this way, and only afterwards "resolved" into two separate stars in more powerful telescopes. The method is therefore a well-tried one and the only strain on our credulity, in the case of distant universes, is in the greatness of the speeds indicated. This is a point of some importance because it is not as widely realised as it might be that the theory of what is known as the "Expanding Universe" has a solid basis in observed fact.

Without indulging in any theorising whatever, we can deduce that all the more distant universes are running away from each other, and that at some time in the past they were considerably closer neighbours than they now are. There is here a suggestion, if no more, that the Universe was, at the beginning, more densely packed than it now is; and that the act of creation, so far as it can be now envisaged, consisted in the initial change which started the process of expansion. It is the working out of this suggestion, in ways that must be frankly regarded as speculative, that it is the main purpose of this chapter to discuss. The picture to which we are led may not prove to be justified. But we can at least be sure that we are here dealing with the problem of creation on the largest possible scale. The birth of stars and the origin of planets may present other fields for interesting speculation. Yet

it is in the beginning of the vastly larger universes, so lately discovered by astronomers, that we must look for creation in the sense that we are now considering.

The significance of this discovery has been enormously heightened by the remarkable way in which it links up with the new picture of space afforded by the Relativity Theory. Without entering upon any of the main difficulties of this most difficult theory, it may be recalled that it envisages instead of "space and time" what is generally described as a "four-dimensional space-time continuum". Fortunately there is no need, at this stage, to try to imagine the meaning of this last phrase. It is more important to remember that space, according to Einstein's theory, is no longer to be regarded as being of infinite extent. It is supposed to have definite limits, so that travelling far enough through space and time it should be possible in theory to return to the point from which we started. All, however, that here matters is that some eight or ten years ago the astronomer de Sitter discovered that the universe, as envisaged by Einstein, was unstable. Space-time must, he calculated, be expanding—and, if space-time, then space as we see it from the earth.

The peculiar beauty of this theory is that it explains just as much as we want explained, and no more. It is, like any other part of Relativity, an essentially mathematical theory, and it so happens that the mathematical equations on which it is based apply only to those regions of space which contain a negligible amount of matter. The consequence of this is most convenient. The theory provides that space should expand wherever universes are not,

so that the distances between the different universes are always increasing; but inside each universe, space is allowed to remain sensibly constant. Out and beyond our own universe, space may be, probably is, expanding. But the sun can still be pictured as staying the same distance from the stars, and the stars from each other, except in so far as their random movements may dictate; and the earth can still be regarded as securely wedded to its life-giving sun. There is no danger that the invisible bond of the sun's attraction will one day prove to be a slowly lengthening piece of elastic.

Before proceeding to speculate on the new light which this theory may throw on the probable origin of the universe, we may notice the picture which it gives is fundamentally different from the merely straightforward interpretation of the astronomical observations which it confirms. The telescope, aided by analysis of the light reaching us from distant universes, shows that each is rapidly moving away from our own. From this we can argue, but without putting forward any special theory to account for it, that every universe is moving away from all others, with the possible exception of a few universes in its immediate neighbourhood, the smaller random movements of which may be greater than the general tendency of each of them to scatter in space. The key to the difference is in the last two words. The straightforward interpretation is that the universes are running away from each other and that space itself is fixed. According to the "Expanding Universe" theory, the individual universes are doing nothing much in particular.

They are merely being carried progressively apart by an expanding space, just as specks of dust on a balloon become more and more separated as the balloon is inflated, although the specks of dust themselves remain the same size.

Even, however, if we accept as a fact the idea that space is expanding, we are still very far from having a complete picture of what is happening. We know the rate of expansion at the moment, and we can calculate that, if the rate of expansion remains the same, then the universe must double its radius every five thousand million years. On the other hand, we have no information as to what the limits of space may be except that they must obviously be greater than the most distant universes which astronomers can see. If it is found that there is a definite thinning out of universes as astronomers probe further into space (for example, with the new 200-inch telescope in America), then it may be possible to arrive at some moderately satisfactory estimate. But even so we should only know the dimensions and rate of expansion of space at the present time, and would have no direct knowledge of how it had either behaved in the past or was going to behave in the future. It is perhaps well to emphasise this point in order that the position of the leading mathematical authorities should be made clear. They are not so much in disagreement about the origin of the universe, as united in agreeing that more than one origin is possible. Of the various possibilities now to be described no one is mathematically more probable than another. By providing the necessary endowment for the maintenance of giant

telescopes and university professors, man has paid his penny. He can now take his choice from the various theories offered him, and need be guided by no other considerations than theological preconceptions, his own aesthetic preferences (which is another way of saying, likes and dislikes) and the inherent probability of the different theories (which is perhaps another way of saying the same thing).

Only three things are certain. The first is that, according to relativity theory, there is one radius of the universe and one only, which represents an equilibrium position. This is one-half of the original discovery made by de Sitter. It means that if the universe were started in any other position, it would automatically begin either to contract or expand, according to whether it was larger or smaller than equilibrium size. The second certainty is that if the universe was ever in this equilibrium position, it was unstable. This also was discovered by de Sitter, and it means that any disturbance, however small, would be sufficient to tip the balance one way or another. The instability has been likened by Sir James Jeans to that of a stick, balanced on the hand, which the smallest movement will cause to fall down to one side or the other. But this is, of course, no more than a metaphor. The third certainty is the observed fact that, whatever the universe may have been in the past, it is not now in equilibrium. It need hardly be said that each of the pictures which has been put forward satisfies each of these conditions.

We may as well begin with a picture which is unlike all others in that it implies that the universe was without

beginning and will be without end. It is not a very satisfactory picture from our point of view, because it is a bad way to begin a discussion on the creation to say that there was no such thing. If we want to give it a label, Sir James Jeans' description of it as the "Concertina Universe" is as good as any. By this it is simply meant that the universe has been alternately contracting and expanding for an infinity of years, and will go on contracting and expanding "world without end". Naturally the chief appeal of this kind of universe is to those who dislike the idea that everything either ever began or will ever end. But it has also a rather special appeal for astronomers. One of the chief objections advanced to the expanding universe theory is that if we start from a creation at all, then the creation is not a sufficiently large number of million years ago to account satisfactorily even for the development of the earth, let alone of the stars, one of which (the sun) gave birth to the earth. Probably, in the present state of knowledge, it is a little unwise both for astronomers and geologists to indulge in too definite figures. But if the objection is valid, it is more than adequately met by the "Concertina Universe". With an infinity of time at his disposal, not even the most exacting astronomer can find cause to grumble. However, as we are in quest of a creation, we must pass on to consider other suggestions.

The next picture is that recently put forward by l'Abbé Lemaître of Belgium. It is peculiarly ingenious because it attempts to account not only for the fact that the universe is now expanding, but for the birth of the stars as

well. We may call it the "Explosive Creation Universe". Its chief drawback is that it involves a slightly closer acquaintance with Einstein's general theory of relativity than has hitherto been necessary—but, fortunately, only in one particular.

Space-time, according to Einstein's theory, is to be regarded as curved, and the picture which we are asked to envisage is that of a four-dimensional surface (space-time) of an imaginary five-dimensional balloon. This is about as impossible, from a commonsense point of view, as a straight circle or a curved straight line. In fact, it is much better to stop trying to imagine, and to recognise instead that the suggested picture represents nothing more profound than a mathematical analogy. Einstein's curved, unbounded yet finite space-time bears the same mathematical relationship to the five-dimensional solid which it imaginarily surrounds, as does the surface of a balloon to its inside. But when mathematicians ask us to translate such a relationship into a mental picture, they are asking something which for most people is impossible.

Let us grant, then, that space-time is curved, and cease from wondering what such a statement may mean in any other terms than mathematical. The immediate result is that we are given a new picture of the expanding universe. In any kind of expanding surface which we know, the curvature of the surface is progressively decreased as its expansion is continued. This is so (both mathematically and in commonsense) when space, or if we prefer it, space-time, expands. So that, without attempting any

impossible flight of the imagination, we may say that, as space expands, its curvature decreases.

The curvature of space has, however, a second and more fundamental meaning in relativity theory. One of Einstein's most important discoveries was that matter could be represented mathematically as a "hill" in space-time—that is to say, as an area of abnormally great curvature. It is on this purely mathematical discovery that Einstein's law of gravitation is based. Contrary to general belief, Einstein's law is even simpler than Newton's. All, however, that here concerns us is that the curvature of space can at the same time be regarded as an indication of the stage of expansion which the universe has so far reached, and of the amount of matter in any part of it. The general curvature of space corresponds with the stage of expansion of the universe, and a specially great curvature in any part of space with the amount of matter which that part contains.

That curvature should have this dual significance is not in itself surprising, and we may indeed obtain a rough analogy from the surface of the sea. Here also there is a general curvature indicated by the existence of a horizon, and local curvatures in the shape of waves; and the causes of the two types of curvature are quite different—in one case the earth's gravitational pull, in the other the action of wind and gale on the surface of the water. But, because the sea is familiar to all of us, we are not in the least surprised or puzzled that this should be so.

According to Lemaître's theory, the universe started by being very much smaller than it now is—very much

smaller than the equilibrium size as calculated by de Sitter and others. Here, as befits the Abbé's clerical calling, is an essentially active picture of creation. The universe is pictured as having started in a condition which was at the same time arbitrary, highly compressed and unstable. If God, as has often been said, holds the universe in his hand, it must have been a difficult handful at the beginning. It was smaller and, to that extent, more manageable. But behind it was an enormous explosive force, sufficient to carry it in every particular to the condition in which we now see it. No power that we can imagine could have held the universe in its original state. Yet something, at least momentarily, must have done so. Then, if we may so put it, the hand of God was lifted. The infant universe leapt free from divine restraint and began its agelong progress of growth and differentiation.

Yet even in the beginning, according to the "Explosive Creation" theory, there can never have been uniformity. The essence of the Abbé's theory is that God must have squeezed some part of the embryo universe tighter than others. To account both for the appearance of matter and for the present expansion of the universe, the initial explosive power must have been different in different places. Remember that the universe of space has since shot far past its equilibrium position and may, for all we can tell, be going to continue expanding indefinitely. Yet in other places matter represents an infinitely greater degree of contraction. In order to account for the universe as we know it, the Abbé is therefore forced to suppose that local conditions varied in the beginning.

Everywhere there would have been an explosive beginning. But in some cases the explosive movement would have been great enough to overshoot the equilibrium position and give us the expanding universe; while in others an unsuccessful attempt to reach equilibrium would be followed by a falling back into contraction, until contraction had so far proceeded that space had condensed into matter. The original explosion can therefore be made to account for the two most general features of the universe as it is—its perpetual desire for expansion and the fact that it contains matter. More, perhaps, cannot be asked of any theory of the creation; and, as the Abbé's mathematics are unimpeachable, the most serious criticism of his theory is that it seems to many people a little too ingenious to be true. On the other hand, if the universe had a divine Creator, it is surely reasonable to allow him as much ingenuity as the learned Abbé undoubtedly possesses.

Finally there is an entirely different picture of the creation, which we may call "Creation by Toppling". As its name implies, it involves no such drastic intervention on the part of the deity. Instead of a titanic grip moulding an embryo universe until each part of it would explode with precisely the desired degree of violence, God is now only required to give the final push to a stick that is on the point of falling, to put a match to a fire that has long awaited its first flame, to breathe movement into what was before unchanging. There is, in fact, an almost infinite choice of metaphors; and the only reason that they have been here multiplied is that there has been an un-

fortunate tendency, in this particular field of inquiry, for each new metaphor to be hailed as a brand-new theory of the universe—which would give a higher birth rate than can be rightly claimed by even the most speculative branches of modern science. New metaphors are very much more common than new theories, and all that is implied by this particular selection is that the universe should be imagined as having first existed in equilibrium, and then been given an infinitely small push.

In the beginning, it may be supposed, everything was at rest and all the forces which made for movement exactly balanced. All the different universes overlapped and interpenetrated. The universe was one, and so had existed for countless aeons, in which time had no meaning. There was nothing to mark its change. Then, some slight disturbance upset the delicate balance and began the long process of expansion which must continue, not only "world without end", but for infinity—long after our own small planet has met its still distant end. That small disturbance is the nearest, according to this view, that the speculations of modern science can take us to the creation. It was the beginning, not of matter, but of change; and, if the change which is now obvious was the beginning of expansion, it seems not unreasonable to suppose that the birth of the stars was not unconnected with its first slow surges. "God said, Let there be light." The modern astronomer's version is, "God said, Let there be movement"—a crescendo of change to which no limit can be assigned.

It is a conception which is no less dignified and, in some

ways, easier to grasp. It is also, rather surprisingly, the picture to which we are led by the work, along entirely different lines, of Professor E. A. Milne of Oxford. Professor Milne, who is regularly heard in debate with Sir Arthur Eddington and Sir James Jeans at the meetings of the Royal Astronomical Society, refuses to accept the Einsteinian conception of an expanding space-time as the only possible explanation of the observed fact that all the most distant universes appear to be running away from ours. This does not mean that he rejects relativity, but merely that he has preferred to make no assumptions of a theoretical kind. Instead he starts by accepting the apparent motions of the nebulae at their face value. He supposes in fact that all the different universes are really running away from each other, and that they are doing this in a stable, sensible and well-behaved space. The fact that we do not normally meet speeds as great as those involved in such a belief, up to twenty thousand miles or so a second, is of course no reason for believing that they cannot exist. In point of fact speeds of the same order have already been postulated in the world of the atom.

In any case Professor Milne has attempted to devise a theory of the universe which will account for such speeds being real—and he has succeeded in the attempt. Merely working back from the present positions and relative motions of the different universes, it appears that they once overlapped. Moreover, the variations in their individual speeds are such as can be accounted for on the basis of the original random movements of a large number of independent bodies.

One difficulty is that this entirely straightforward picture explains a good deal too much. It is most convenient and plausible that the present behaviour of the universes should lead to the conclusions that they once interpenetrated. But what happened before that? To take an everyday analogy, let us imagine a large number of tennis balls flying apart in all directions. From the way they are travelling we can conclude that a few seconds before all their different paths passed within a few feet of one another. But if we carry the same analysis a little further back, we shall have to explain how such a random swarm of tennis balls came into being. We shall find that a few seconds earlier the same tennis balls were rushing towards one another at the same speeds and in the same directions as we originally saw them flying apart; and the further back we go the more remarkable does it seem that so many different balls should have been thrown in so many different directions at so many different speeds in such a way that they should all come roughly together at the same instant.

This difficulty is fortunately removed by finer analysis. The universes cannot really be considered as a swarm of tennis balls flying about quite independently of one another. As we have already seen, the distances between many of the different universes are, even now, relatively small, and in the beginning they must have interpenetrated—a state of affairs which we can hardly imagine in the case of tennis balls. The obvious difference, that whereas a tennis ball is solid a universe is not, is also the most important. The gravitational pull of each universe

on the others must have influenced, not merely the movements of each, but the form of each as well. We may even imagine that the birth of the stars was in some way connected with this mutual interaction. As the still formless masses of the different universes wandered through the equally formless mass of another universe, powerful eddies must have been set up, which we may well suspect had a direct connection with the local concentration of matter in the shape of embryo stars. Conversely any local concentration of matter would have its own effect in stirring up further eddy movements beyond and around it. Similarly the greater closeness of the stars would, as we shall see in another chapter, make the birth of planets more probable.

Starting with a single formless universe it seems at least possible that Professor Milne, or some follower, may be able to build up a theory which will account for both sets of changes—the segregation of the different universes from the one, and the concentration of the different universes into stars as the segregation proceeded. Like Einstein's theory of relativity, which as we have seen may equally well be used for this purpose, such a theory would represent an important feat of generalisation. It would, at one and the same time, explain the two most important aspects of astronomical creation. The origin of the different universes is the largest-scale problem. Logically, therefore, that should come first. But if the birth of the stars, the next largest sort of beginning, can be explained at the same time, so much the better. If the same theory can also account for the birth of planets, in particular of

our own, it will have done all that anyone could reasonably ask of it.

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Man has paid his penny. He is now free to take his choice between the "Concertina Universe", with neither beginning nor end; the "Explosive Creation Universe", with a clearly marked beginning to which we can trace our way back, but for which we could never hope to account; and the "Toppling Universe", in which also there must have been one definite moment which can be most naturally identified with creation, but in which that one definite moment is as unspectacular as the first stirring of wind among the trees. Each of these pictures caters for its own type of theological taste. The natural tendency of scientists, so far as we can generalise at all about such diverse people, is probably to prefer either the first or the last. The "Explosive Creation Universe", with its cataclysmic beginning, would on the whole be regarded with slightly greater suspicion; for although, as a political slogan, the inevitability of gradualness is to-day slightly discredited, scientists will always tend to prefer gradualness, even while increasingly compelled to admit that it is not inevitable. But in the end, as has already been said, the choice of the favoured picture of creation must be left to personal taste.

In conclusion, it may be of interest to notice how our idea of creation has altered as discussion has proceeded. We started, it may be remembered, by deciding that a merely material creation was a conception of remarkable difficulty. Led outwards into space in the wake of astronomical discovery, we began to look for beginnings on a

larger scale than anything on this earth could directly suggest. Yet it was only when we obtained definite information from the telescope that the universe was expanding, that we called in the abstract theory of relativity to explain what we had seen. And in the end we have been led back, at least in part, to the idea of the creation of matter itself. It is true that only one of our pictures made any claim to account for the beginning of matter, and that only in the most general terms. But the mere fact that matter is regarded, in terms of relativity, as a form of curvature in space suggests that the future material content of the universe must have been in some way specified in the sort of beginnings that we have been considering.

From another point of view also it appears that our original decision to ignore the creation of matter as such was a wise one; for, if matter is merely a special manifestation of space-time, then space-time is the only fundamental. Now it is not very easy to imagine that space-time never existed. We can imagine nothingness, even a uniformity of nothingness—but not "no-where". It is probably simpler to suppose that space-time has always existed; that the proper place to seek for creation is in the initial changes which transformed a stable, uniform space-time into a universe which is both expanding and contains matter. It so happens that the remoter of these two problems, that of the expansion of space itself, is the easier of solution. So by ignoring, for the most part, the more obvious problem of the creation of matter, we have been able, paradoxically, to make a nearer approach to the beginning of things.

CHAPTER III

ARE THERE OTHER WORLDS THAN OURS?

ARE there other worlds than ours? The very question raises memories of Martian warfare, as depicted by our more sensational novelists, and of those even more convincing maps which show the lay-out of the same planet's canal system. Such imaginings have their romantic appeal. They are also inevitable and time-honoured. Ever since it was discovered that the planets were sister bodies, some greater, some smaller than the earth, all like the earth circling round the same warmth-giving sun, it has been natural for men to inquire whether some one or more of them might not be inhabited by beings, at least thinking and feeling, and perhaps looking out into space as we do through instruments of their own devising. Not at once were such imaginings crystallised into words. The earth had been too long the centre of the universe, man too long the undisputed lord of creation, for any serious rivalry to be immediately contemplated.

Something more concrete was needed to stimulate speculation. It was provided by the so-called canals of Mars, first reported in 1877 by Giovanni Schiaparelli, director of the Milan Observatory. To-day, paradoxically enough, there are relatively few astronomers who believe

in Schiaparelli's canals. Yet the main question remains open. Is there life on some one or other of the planets? Or must we believe that our world, alone of all the worlds in the universe, has given birth to life—that not one among the hundreds of millions of stars can boast a second earth? As so often, on the borders of scientific knowledge, it is a question of weighing evidence and balancing probabilities; and in the end proceeding, with some show of justification, to back our personal fancy. But we shall at least be able to back our choice with argument and to know in advance the counter-arguments which may be expected from any likely opposition.

Let us look at the facts, so far as we know them to-day. We may begin by asking the biologist what are the basic essentials for the existence of life; and, if he is at all an earth-minded biologist, we may take the opportunity of reminding him that under different conditions life might have evolved very differently on another planet. Even on our own planet the camel's hump has developed as a desert food reserve. Mammals have successfully adapted themselves for flight, as in the case of the bat, while the whale has been even more successful in the sea. If we want a still more striking example we may remember that there are certain bacteria, which live only on nitrogen and, unlike almost all other forms of life, have no need of oxygen at all.

None the less even the most imaginative biologist would find it difficult to picture any form of highly organised life without both oxygen and water. Burning is the most general way of obtaining energy that we

know of, and burning is nothing more than the combination of oxygen with other chemical elements. The only exception is that the heat energy of the stars is probably derived from the "transmutation" of matter. Every machine in the world derives its energy, in the last resort, from burning, with the exceptions only of those electric motors which happen to take their current from a hydro-electric system and the relatively few mills which make direct use of water-power, and even more rarely of wind-power. To this golden rule our bodies are no exception. We live and move and think on the energy provided by burning our food. We breathe in air, and breathe out carbon dioxide, the product of burning carbon to completion. It is certainly difficult to imagine tha. any complex organism could obtain the energy necessary for life by any other process than burning—although it does not follow at this stage that the something burnt is carbon.

It is equally difficult to imagine life, or at least complex life, without water. It is so ordinary a substance that we are apt to take it for granted. But as Professor C. M. Yonge has pointed out, water is almost perfectly fitted, in quite a number of different ways, for the control of living matter. It is, in the first place, the best solvent that we know. In both plants and animals it is present to carry chemicals from one part of the organism to the other, so that every kind of activity can be stimulated and controlled. It is, moreover, exceedingly stable chemically, so that it can be relied upon not to interfere with the various chemicals with which it is entrusted.

Indeed so far from interfering with them, it is itself an important agent in promoting chemical change within the body. And, as if this were not enough, water plays a further important part in maintaining our bodies always at the same temperature. This, again, is a quality which on the earth at least has proved essential to the most complex and successful forms of life. All chemical changes are greatly influenced by temperature, and so for the smooth running of the body's machinery it is obviously desirable that the temperature should be kept constant. The physical properties of water might well have been designed for this very purpose. It is remarkable for the large amount of heat which it requires both to raise it through a given temperature, and also to vapourise it. The first property is important because we are very largely made of water and therefore difficult to heat up; and the second because the evaporation of sweat from our skin is nature's way of avoiding over-heating.

Oxygen, then, and water we may reasonably demand as the first two essentials for the existence of life on any other planet. The laws of chemistry also set a limit to the degree of cold which could be tolerated if activity were to be maintained, while it is obvious that no form of life could withstand a sufficiently hot furnace. The most obvious limits are, however, those of bodily temperature, rather than of conditions outside. If, for example, the body makes use of water to any considerable extent, then it is evident that the internal temperature must be somewhere between freezing and boiling point. Indeed even a close approach to either limit would

make it extraordinarily difficult to design a suitable body. On the other hand, if man had happened to evolve with an asbestos skin, which is by no means outside the bounds of possibility, he would have been able to withstand a considerably greater range of external temperature than he now can. The outside temperature, it is true, could not be higher than the boiling-point of water, or he would not be able to obtain supplies of that most necessary fluid; but temperatures far below zero would be perfectly possible, especially if an arrangement of "warming up" pipes was provided to heat the air on its way to his lungs. The effect of the latter would be to protect the lungs against damage. There would still be a considerable heat loss, due to the difference in temperature between the cold air that was being breathed in, and the warm air that was being breathed out. But even that could be reduced. The heat from the warm air could be used to warm up the cold air on its inwards journey.

Certainly it is easier to imagine life on a very cold planet than on a very warm one. Not only are the possibilities greater. The natural history of planetary systems points in the same direction. As the star, which is the planet's sun, grows colder, so also must its planets. If, therefore, we imagine a complex form of life now existing on a hot planet, there must in the past have been a simpler, less well-protected, form of life existing under still more difficult conditions. On the other hand, if life had originated when conditions were more favourable, we might picture a gradual process of adaptation to steadily increasing cold. If these other-world beings are to be

intelligent, as we have been imagining, we may suppose that their evidently impending fate would be met by such concentrated and united endeavour as we, on this earth, have yet to see.

Let us suppose that, thousands of millions of years hence, the heat of the sun has so far failed, that there is perpetual ice even on the equator. Would it not be possible that man should still live a successful and happy existence, even under what must appear to us entirely unnatural conditions? Might he not live, as has been suggested in more than one popular forecast, in great underground cities? Ultra-violet lamps, such are already obtainable, would carefully mimic perpetual sunshine. Plants and animals would have long since disappeared from the surface of the earth. But might they not still live and flourish in this underground world, in which there might be perpetual spring, summer or autumn according as its scientific dictators thought fit? Perhaps plants and animals might be no longer necessary. All man's food requirements could be built up by chemists, and made, together with his clothing, in super-model factories.

There would still remain, it is true, the energy problem. The world's coal and oil supplies would, it may be presumed, have been long since exhausted. Water-power would have been reduced to frozen inactivity. But the problem would represent no sudden emergency. It would have been foreseen millions of years in advance. It would have been the subject of numerous world conferences, meeting in the only atmosphere which at present seems

capable of producing unanimous action. All sectional interests would be united, as time wore on, by what Mr Rudyard Kipling has called the "Ties of Common Funk". Scientists would no longer have to appeal for financial support for their laboratories. They would on the contrary be provided with unlimited equipment, and urged to work extra time. Perhaps there would be so many scientists that not even that would be necessary. Certainly it is reasonable to believe that they would find the solution of the underground-power problem—perhaps in the transmutation of matter, in ways of which we do not yet know; perhaps along some entirely different line of research of which we have not even an inkling. And when that problem had been solved, there would be no other factors which should present insuperable difficulties. Under present economic and social conditions human labour and technical skill are only being utilised to perhaps 20 per cent. of their capacity. If fear drove, the necessary underground cities would be built.

Such being a perhaps not too imaginative forecast of the history of the human race,.may we not believe that even on planets, on which the thermometer never rose above −100 degrees, some race as intelligent as ourselves, perhaps more intelligent, might still manage to keep body and soul together? At least it is possible, and in our search for possible worlds, we shall certainly do better to allow greater latitude in regard to cold than we can in regard to the scorching heat of some too near sun.

If we begin our quest within our own solar system, we find that most of the planets can none the less be ruled

out at once on the score of temperature. Mercury, which is nearest the sun, is so hot that even zinc would melt on its surface. The giant planets, Jupiter and Saturn, are generally admitted to be too cold even on the most generous estimate of the conditions necessary for life. The outer planets, Uranus, Neptune and little Pluto must be inconceivably colder. There remain Mars and Venus, the next-door neighbours of the earth on either side, the one a perennial source of speculation, the other for ever shrouded in mystery.

Mars must certainly be a chilly place, judged by earthly standards. It is true that the temperature rises during the daytime to about 50 degrees Fahrenheit. But by sunset it is already freezing, and during the course of the night the temperature drops another 150 degrees or so. If the day temperature, on parts at least of Mars, is perfectly comfortable, the range between night and day conditions must be at least twice as great as anything of which we have knowledge on earth. The last watch before dawn would be one of almost inconceivable hardship for a Martian sentry, if he were modelled on anything like human lines. But there is no reason why our Martian neighbours, if such exist, should not have devised adequate means of protecting themselves against the night cold. Consequently, although there is still a certain amount of divergence between different estimates of temperatures on this planet, it may be taken as definite that Mars is warm enough to support life in some form.

Mars being certainly warm enough, we have now to ask whether it has an atmosphere and, if so, of what kind.

The first question is one that can be answered, up to a point, from purely theoretical considerations. Any ordinary gas, we know, always tends to spread itself out so as to fill the largest possible volume, which in the case of a planet can mean nothing less than the whole of space. Our own atmosphere is only prevented from dissipating itself in this way by the gravitational pull of the earth, so that a comparison of the force of gravity on the surfaces of the earth and of Mars provides an immediate indication of the extent to which the latter planet should be able to retain an atmosphere.

It so happens that the force of gravity exercised by different planets is one of those astronomical quantities which we can calculate with certainty—at least within quite a small margin of error. Very conveniently, any spherical body, including a planet, behaves for gravitational purposes as if its mass was entirely concentrated at the centre. This most convenient discovery was one of the most important mathematical triumphs of Isaac Newton. It enabled him to prove that the earth's gravitational pull on the moon was governed by the same law as its gravitational pull on a falling apple. It also enables us to calculate the strength of gravitation on the surface of any planet, provided that we know its mass and radius. The masses of the different planets, relative to that of the earth, can be calculated from their motions in the sky. Their size we can tell from direct observation through a telescope provided that we know how far away they are. It turns out that the gravitational pull on the surface of Mars must be about two and a half times as

small as that on the surface of the earth. Without any more subtle astronomical observations, we could therefore be certain that the Martian atmosphere must be considerably less dense than our own. We could also be fairly certain that Mars had an atmosphere of some sort because we have no reason to suppose that its history differs substantially from that of the earth, except in so far as it is smaller and farther from the sun.

There is, however, direct proof that Mars has an atmosphere. Perhaps the most obvious piece of evidence is provided by the fact that markings on the planet's surface appear relatively less clear when they are near its edge as viewed from the earth. This is because we are then looking at them obliquely, that is through a greater length of Martian atmosphere. The difference represents nothing more erudite than the fact that, if we cut a thin slice from an orange, we cut through a lot of skin, whereas if we cut through the orange in the middle we cut through relatively little skin. But it does suggest that there is a skin to be cut. In addition, moving white marks have been observed, apparently above the planet's surface, which it is difficult to interpret as anything but clouds. Still more convincing is the fact that analysis of light reflected from Mars indicates the presence of both oxygen and water vapour, although the amounts found are only about one-seventh of those in the earth's atmosphere. The conclusive observation that the Martian atmosphere contained water vapour was made by Dr V. M. Slipher at the Lowell Observatory at Flagstaff, Arizona. Founded for the special purpose of planetary observation, this

observatory has done more than any other to elucidate the vexed question of whether there may be life on the planets.

Mars is therefore not merely possible from the point of view of temperature, but contains in its atmosphere the two constituents which we agreed to regard as essential for the maintenance of life in any highly organised form.

But what, it may be asked, of the famous "canals" of Mars? If they were real, and could only be explained as being of artificial construction, there would be no further need of discussion. The existence of life on another planet, and that of a high order, would have been proved. Unfortunately for any such hope, the "canals" cannot be presented, at the best, as anything more than a large question mark. The very word is misleading. When Schiaparelli observed what he interpreted as a network of lines crossing the surface of the planet, he christened what he saw "canali". Now "canali" is merely the Italian for "channels". The term conveys no implication of artificial construction, and in point of fact Schiaparelli believed to the end of his life that his "canali" were natural features of the Martian landscape. It is, however, by no means certain that they are even there to argue about.

The most convincing argument against the reality of the "canals" is provided by a very simple experiment which was carried out many years ago by a Greenwich astronomer, with a number of Greenwich school children as its subjects. To show that the "canals" might be an optical delusion he presented the children, seated at the

far end of the room, with a map showing the physical features of Mars, but without the canals. He then asked the children to draw what they saw—and many of them proceeded to draw in a canal system very similar to that which a number of astronomers claimed to have seen on the planet's surface. The experiment clearly proved that it must be easy enough to imagine canals on Mars. But even if the so-called canals were a real feature of the Martian landscape, there is still the difficulty that the construction of "canals" wide enough to be visible at a distance of fifty million miles, and long enough in the aggregate to girdle the earth many times over, would be altogether too formidable a task for even the most "sentient beings". A further point which is often conveniently ignored is that the engineering difficulties involved would be made even greater by the presumed hardness of the Martian subsoil, owing to the low average temperature.

It is, perhaps, only fair to add that there are still many astronomers who maintain that the canals are real, and a rather smaller number, including Dr Slipher, who believe that they may be artificial. The instability of our own atmosphere is the explanation of the fact that no decisive test appears possible. Owing to eddy currents in the air, it is impossible to use more than a certain degree of magnification to any advantage with even the largest telescope. A giant telescope has more light-gathering power, and will therefore show fainter objects. But it cannot be used to show more detail on the surface of either the moon or the planets.

If we want direct evidence of the existence of life on Mars, we must not fly higher than the plant world, although we must seek it, paradoxically enough, in the Martian "seas". The seas, like the canals of Mars, are a misnomer, although it is possible that the dark areas in question were once really seas. If they were ever filled with water, this must have long since evaporated in the rarefied Martian atmosphere. But whether or not their name was ever deserved, the "seas" of Mars do to-day go through a most interesting series of seasonal changes. Not only does the degree of darkness of these areas vary, but their colour as well. As the polar caps disappear in the Martian summer, the "seas" near the equator become green. Later the green is transformed into brown, and the brown in turn fades away. Have we here the spring, summer and autumn of plant life? Other explanations may be possible, yet the idea remains tempting. It is supported by the discovery of the gas ammonia, a universal product of the decay of vegetation, in the Martian atmosphere. Proof that there was plant life on this planet would not imply that there was animal life as well. But it would remove an obvious impediment. For it is exceedingly difficult to imagine animal life in the absence of vegetation. All animal life, including in this term both insects and fishes, is ultimately dependent on plants for its food. It seems that here again there is no insuperable difficulty in imagining that there is life on Mars.

Before taking leave of this most intriguing planet, we may notice one or two other particulars in which life on Mars would differ from life on the earth. Apart from

the extreme dryness of Mars and its cold night temperatures, a visitor to Mars would be at once struck by the peculiar appearance of the sky. He would notice, if he was an Englishman, that clouds were relatively uncommon. But he would probably be even more impressed by the darkness of the sky. The light blue of our own sky is due to the very large amount of the sun's light which is scattered on its journey through the atmosphere. It so happens that blue light is more completely scattered by small particles in the air than is red light. The result is that a clear sky appears blue, and so it would appear on Mars. But owing to the rareness of the atmosphere, a relatively small amount of light would be scattered. Consequently the sky, although blue, would be more like navy or indigo than the delicate azure with which holiday advertisements attempt to lure us to seaside resorts. If the atmosphere were inappreciable, as on the moon, the sky would look black, for only the sun's direct light would be received.

At night our earth visitor would be even more struck by the eccentric behaviour of the two Martian moons. The larger moon, which must appear as a disc of only one-sixtieth of the size of our own moon, has the peculiar distinction of rising in the west and setting in the east. In this short time it also changes from new to full moon or *vice versa*. It is also so near the planet that its brightness varies with the position of the observer. The behaviour of the fainter of the two Martian moons is almost equally odd. Once up in the sky, it remains there for three whole days, and during that time it is twice "new" and twice "full".

The effects on all forms of athletic endeavour of Mars' relatively small gravitational pull are perhaps more familiar. With exactly the same effort that is needed to jump 20 feet on earth, a man could jump more than 50 feet on Mars. Nothing less than 55 feet could be rated as a good "long-jump" performance, while nothing less than 16 feet would be regarded as at all exciting by an ambitious high-jumper. In the case of a game such as tennis, it would be difficult, save by the most arrant pat-ball, to keep the ball within a court of our present size. On the other hand, the ball would also bounce two and a half times as high, so that the situation might be to some extent met by taking everything as a smash. Such examples could be multiplied indefinitely. But as we are not yet sure that Martians exist, much less that they indulge in athletic contests, we may perhaps leave it at that.

So much for Mars. It is the only planet of which a detailed discussion is possible from this point of view. The position in regard to Venus is very much less satisfactory. If its silver orb is an object of beauty to the layman, it has proved singularly tantalising to astronomers. Its surface is permanently hidden in cloud. We do not even know how deep the cloud layer may be, much less what conditions on the surface of this planet may be like. All that is certain is that its climate must be very different from that of the earth. As the earth's nearest neighbour on the other side, that is towards the sun, we should naturally expect that it should be hotter, although not tremendously so. Probably it is both hot and humid. But however uncomfortable it might be for human

beings, we certainly cannot say that it would be unsuited for life of some kind. As for its atmosphere, we know that it is there, and not much more. Neither oxygen nor water vapour has yet been detected. But this is purely negative evidence, and has little real significance. It may be that our analysis does not go deep enough—in a quite literal sense. If the sun's light were reflected to our telescopes from high up in Venus' atmosphere, it would naturally give us no knowledge of its lower layers.

We are wholly dependent for our knowledge of the planets on the sunlight which they reflect. The only prospect of penetrating farther towards the surface of a cloud-ridden planet, is by making use of the most penetrating rays of sunlight, those of the infra-red variety. Just as they will pierce fog on earth, so they will reach farther down through a planet's atmosphere. But special photographic plates are necessary to record them. Plates of this kind have been enormously improved in recent years, and still further advances are no doubt to be expected. So in the long run it looks as if astronomers may be able to lift, at least in part, the veil of cloud in which Venus has so long lain hidden. For the present, the only positive statement that we can make about the atmosphere of Venus is that slight but definite indications of carbon dioxide have been found. This suggests that life-giving oxygen may one day be detected. And with that rather meagre hope we must take leave of the most tantalising of all our sun's planets.

What of the planets of other stars? Within our sun's system we have found, at any rate, two planets which

might possibly support life of some kind. Surely the thousands of millions of stars now known to exist must have considerable planetary offspring? Surely some at least of these other planets must be inhabitable? So it would seem at first sight. Yet, until quite a few years ago, there was no reason to believe that the stars had been so fertile in the production of planets as might be imagined. According to the most plausible theory which astronomers have yet produced, planets are only born when a big star passes sufficiently near a small star to draw out planets from its surface by sheer gravitational attraction. This theory, based on the drawing out of a cigar-shaped mass from the sun's surface, has the merit of accounting, more or less exactly, for the relative sizes of our own planets. But in its original form it also implies that the birth of a family of planets must be a very rare event indeed. On the basis of the random wandering of the stars, Sir James Jeans calculated some years ago that it must happen, on the average, about once every five thousand million years. That would be far too small a birth rate to be of much practical assistance in our search for living worlds. Out of all the multitude of stars, the probability that any one of them possessed a life-bearing planet would be barely equal to the probability that there was life on Mars or Venus.

Sir James' calculation was, however, made before the discovery that the universe is expanding. It is a discovery which makes it at the same time considerably more probable that other stars may have had planets drawn out from them, and at the same time quite impossible to

calculate to how many of them this may have happened. The universe appears to double its radius every 1300 million years. That sounds a long time. But remember that the earth itself is believed to be 3000 million years old. Space was very much smaller when our sun's planets were born, while at the beginning of the long process of expansion the different universes of stars are supposed to have overlapped and interpenetrated. This was somewhere of the order of 10,000 million years ago, not so enormously different from the age of the earth as we are now measuring time. It may well be that our own planet's birth belongs to this earlier stage of stellar evolution. Or, if its birth was later, it would at least seem probable that a considerable number of other planetary systems should have been born before ours was thought of. But we have no means of telling how many. We simply do not know enough about what the universe was then like.

So it comes to this. Within our own sun's system, we have Mars and Venus as possible life-bearers, and outside it an unknown number of other planets, some of which at least may be supposed to be in a fit condition to support life of some kind. It may be that other planets are destined to be born from other stars, in which the candle of life will in turn be lit, to burn fitfully for some 50,000 million years until an answering flicker will have appeared on some other planet of some other star. It may be that physical life is more nearly eternal than even the vast heat reserves of our own sun would suggest. But it looks on the whole as if most of the planets that are ever likely to be born must be already in existence; and that life would

be born and die on them at periods not so enormously removed from its appearance and ultimate death on earth. In any case we can, with rather more certainty, believe that we represent one of the earliest experiments in intelligent life. If the age of the universe has been estimated with anything approaching accuracy, there could hardly have been time for life to wax and wane to cold deadness in any other planetary system. Our supremacy may be disputed by intelligent contemporaries in other worlds. We can have had few, if any, predecessors.

Are there other worlds than ours? In the last resort the question is resolved, like so many others, into one of personal preference, coloured inevitably by the theological outlook of the individual. How did life on our own planet originate? Are we to believe that, at a certain stage in the earth's history, conditions on its surface became such that life spontaneously arose—or that the beginning of life represented an independent act of creation? If we adopt the latter viewpoint, discussion is inevitably limited. We have seen that conditions suitable for the maintenance of life are, in all probability, to be found on other planets. But it would be a bold man who would attempt to decide, from *a priori* reasoning, whether a Creator would or would not elect to put life upon them. Perhaps it would be most natural, so far as we can judge at all in such matters, to suppose that there would have been more than one experiment in living creation. But it would be an entirely unscientific conclusion. The most essential datum, knowledge of the mind of the Creator, is unfortunately lacking.

We may, on the other hand, hold to the opinion that life arose spontaneously when conditions on earth were ready for it. That is a view which is in no way inconsistent with the divine origin of the universe, and therefore of man. But it involves the difficulty that no biologist has ever succeeded, even with the enormous range of laboratory technique available, in finding the conditions in which the simplest forms of life can originate. It does not, of course, follow that it will always remain impossible to do so. But it does seem that the recipe for producing life must be exceedingly complicated, the necessary conditions for its spontaneous arising a rare accident—at least from a human point of view. How rare we could never tell until we knew what the necessary conditions were, that is until we had produced life ourselves. So it appears that the answer which we are seeking depends once again on an unknown quantity. There are other worlds which may be inhabited. We cannot tell if they are inhabited. We may be unique specimens. On the other hand, we may appear to the inhabitants of some wiser planet as lamentably inferior creatures. It can only be left to our vanity, or lack of it, to decide.

CHAPTER IV

THIS CHANGING WORLD

It is little more than a century since man discovered mountains as anything more than an obstacle to transport or a home of the supernatural. The Greek gods had lived in Olympus. From another mountain had been brought down the tables of the law. On the Brocken in Germany there dwelt a giant shadow spectre, and in every land mountains have been, in man's imagination, the home of strange and wonderful beings. Long after the old gods have died, the little gods and trolls have lingered on amid their unfrequented steeps; and, so long as the local people were afraid, there could be no guides to encourage travellers on their way. Mountain passes might be used as an unavoidable alternative to level walking. But, whether from fear of gods or goblins, the heights above were no place for human feet.

To-day the last battles in the long campaign are being fought. Only here and there, it seems, are the mountain gods still powerful, although every range frequented by climbers takes its annual toll of life, through mist and avalanches and treacherous snow. For the true climber, no doubt, part of the attraction is represented by the peculiar mixture of danger and endeavour which mountains provide. Nature is being met, and on the whole conquered, on her own terms.

But for those others who know nothing of climbing irons and ropes, there must be some other attraction than the mere acceptance of a challenge. It is, perhaps, that in this world of changing values and fortunes, mountains stand for something sure and immovable. They, we feel, will never bow their heads. The wind may blow and thunder-clouds invade their peaks. But the next day, as likely as not, the air will be calm and the sky clear. The mountain takes no more notice of the one than of the other. Theirs is a philosophic poise which the average human lamentably lacks. Part of the earth, they are solid as the earth. So at least it seems. It is the purpose of this chapter to examine how far such appearances are justified; to seek for traces of changing continents as well as of changing mountains; and to show that here also there are many problems that are unsolved.

It was from mountains, paradoxically, that there came the first suggestion that this world of ours was changing. Scientific observers travelling in the Alps could hardly have failed to notice the crumpled and broken forms of its rock strata. A rock-face which has suffered violent upheaval carries its own message. But the conclusion which the earliest geologists drew was only partly correct. They believed that once, in the far past, there had been a universal cataclysm, no doubt connected with the flood of the Bible story; and that, the visitation over, the earth's crust had thenceforward settled down to a stable and well-behaved existence. We may not yet know how mountains are born. But we do know that they are of very different ages and have suffered many different upheavals;

that rain and frost are continually wearing them away; and that whole countries, mountains and all, have been alternately raised and lowered within the period covered by the record of their rocks.

There is no need, however, to go outside the bounds of history to find changes of significance. Rather more than a century ago Sir Charles Lyell, then an Oxford student, noticed that a small lake on his father's Scotch estate was capable of depositing an appreciable layer of limestone on its bottom within quite a few years—and on his discovery that rocks could be built up as well as worn away is based a large part of modern geology. Later, on a visit to Georgia he noticed how rapidly valleys could be eroded when forest country was being cleared by settlers and rain water flowed more rapidly away. That is another side of the same picture. Rivers can wear away rock as well as earth, and in the debris which they carry with them is the material for the building of new rocks beneath the sea. The United States alone, it is estimated by Federal geologists, is robbed of 783 million tons of its native soil every year in this way. Since the Declaration of Independence was signed in 1776, it must have lost the equivalent of a mountain seven miles across at its base and rising to a height of 4500 feet above the surrounding country. But all this material is not necessarily wasted. Not merely is the level of the sea bed at river mouths being progressively raised; but, according to modern theory, the increasing pressure on the adjoining ocean bed is responsible for forcing up new mountain ranges on the mainland.

Contemporary evidence of other kinds of change is naturally not lacking. Swedish surveyors have, for example, observed that the whole of Scandinavia is gradually tilting from north to south. Compared with sea-level, it appears that the north of Scandinavia is rising at the rate of about four-tenths of an inch a year, quite enough to be accurately measured, while the south-western end of the peninsula remains at the same level. Similar changes are taking place in the level of Finland on the opposite side of the Baltic, so there is good reason to believe that the movement, if slow from a human point of view, is also widespread.

Similarly there is a certain amount of evidence that England is tilting—from north-west to south-east. Borings in the buried channel of the Thames show that where our forefathers of the Late Stone Age lived and worked is now some 60 to 70 feet below sea-level. It follows that the neighbourhood of London has been sinking, during the past ten thousand years, at the not very impressive average of 9 inches in a hundred years. Is it still sinking? The most recent measurements suggest that it is, although it is difficult to disentangle a small long-period movement from local changes due, no doubt, to deep excavations, the gradual drying of the subsoil with improved drainage, the diversion of subterranean streams and perhaps the lowering of the water level in the chalk as increasing supplies are taken through artesian wells. Another line of evidence is perhaps more suggestive. Just as the level of Stone Age finds gives an average sinkage of 9 inches in a hundred years, so calculations based on Roman

remains suggest a similar figure. It seems, therefore, that within the last ten thousand years, London has been sinking at a more or less uniform rate. Presumably it is still doing so to-day, although it will be another five hundred or a thousand years before the problem of maintaining the Thames embankment will begin to become acute.

All this applies only to London itself. It is in agreement with the idea that England is tilting as a whole, but by itself proves nothing. The only general evidence is provided by the two national "levellings" undertaken by the Ordnance Survey. The first was begun in 1840 and the second in 1921 and, whatever the reason, there are appreciable differences between the relative levels found on the two occasions. It is quite possible, and it was at first believed that this was the case, that the discrepancies are entirely due to a cumulative error in the original measurements. On the other hand, taken at their face value, the records indicate that England is indeed tilting and that the south-eastern counties are now one and a half to two feet lower than they were in 1850. This is a considerably greater rate of change than London's slow sinking through ten thousand years, and the explanation which has been put forward is not very satisfactory. It is that there has been a general but smaller movement of the kind indicated; but that the apparent extent of the movement has been magnified by mistakes in the original levelling. The verdict of the scientific world is "Not Proven", and the Survey will have to wait another fifty years until the next "levelling" before they can obtain

conclusive evidence one way or the other. The main difficulty is that the movement, if real, is so much slower than that of Scandinavia. Also, in this as in other cases, it is not easy to disentangle the supposed general change from purely local movements.

Coastal erosion proceeds very much more obviously. The classical example is provided by the fate of Dunwich on the east coast of England, once a flourishing town with a cathedral and eight churches, which has now lost the last of its churches and is a town no more. Elsewhere the sea is retreating behind a barrage of sea-borne mud, and sometimes both processes may be seen simultaneously proceeding within a few miles of each other.

Even the growth of mountains is undoubtedly a contemporary movement. It is certain, for example, that the Himalaya are still rising, so that the longer it is before Mount Everest is conquered, the greater by a few inches will be the honour of the climbers. Making mountains out of molehills may, in a human being, be a sign of weakness. In nature it implies an almost unbelievable strength. In the making of even the smallest of mountain ranges the most titanic forces must be called into play. Imagine how much a firm of contractors would ask to add even ten feet to the whole of the Rockies. Yet nature has raised the whole—from nothing. And we have very little real idea of how such feats are performed.

The traditional analogy used to be the wrinkling of the skin of an orange as the fruit dried up inside. So, it was supposed, as the earth slowly cooled and contracted, the solid skin on the outside was forced to accommodate itself

to the smaller area available. There would not be room enough for the rocks in their original flat layers, and they would be forced up and even twisted in places as the extent of strain varied on the earth's surface. Then came the discovery of radio-activity, and with it the realisation that here was an unexpected source of energy within the earth itself. As radio-active elements in the earth gradually broke down into simpler atoms, it was known that energy must be released, and it began to appear that the inside of the earth might not, after all, be getting progressively cooler.

It became fashionable, therefore, to direct attention instead to the enormous pressure which must be exerted on the ocean bed in the neighbourhood of continents by the silt and stones which the continent is regularly losing to the sea. This, it might be supposed, was connected with the forcing up of new mountain ranges along the edge of a continent; and, in the case of America, it was possible to point to the long line of the Rockies and the Andes and to say that they might have been formed in this way. But even in such a straightforward case the problem can hardly be said to have been solved. The pressure on the ocean bed is essentially a vertical one, downwards, whereas a sideways force is what is necessary if mountains are to be squeezed up on the neighbouring mainland. Such a theory can, in any case, hardly be used to explain the enormous and complicated rock folds found in such a range as the Alps, if indeed such a tangled mass of mountains can be called a range at all.

To-day, although the main problem of mountain

building is still unsolved, a large part of the world gets all too frequent reminders of the enormous forces involved. Earthquakes are no more than the growing pains of mountains; and both in human affairs, and from the point of view of our world picture, their importance is altogether out of proportion to the relatively small movement involved. Although earthquakes have been responsible, so far as we can tell from old records, for the death of more than a million human beings in China alone within the last four hundred years, the maximum extent of the earth movement is often no more than a fraction of an inch. In fact the greatest up-and-down movement ever recorded was one of only 4 inches during the Japanese earthquake of 1891, although there was a sideways rocking of as much as 14 inches on the same occasion. The damage is caused, not by the movement as such, but by the rapidity of the vibration and the great force behind it. A movement of less than a thousandth of an inch can be distinctly felt, and the upward force of quite a small earth movement may be sufficient to shoot a heavy flag-pole several feet from the ground.

The geographical distribution of earthquakes provides the clearest possible evidence that the rise of mountains represents a local straining of the earth's crust. The world lines of earthquakes are practically coincident with the lines of greatest mountains. One line starts in Southern Europe and proceeds via the Himalaya to the Malay archipelago. At the north of Australia this line forks, one branch passing roughly down the east coast of Australia and the other east and south across the Pacific. Here the

mountains which are the cause of the instability are reared, not from solid land, but from the ocean bed. But the fact that only their peaks may be visible does not make the main mass of the mountain any smaller. Near Fiji and Samoa, and in a line with the latter, are the Tonga and Kermadec deeps, two valleys which reach almost as far below sea level as Mount Everest does above it. Yet what visitor, standing on one of the islands of those names, would realise that he was near the summit of one of the world's greatest ranges?

The second earthquake line follows the west coast of South and North America, along with the Andes and Rockies, for practically its whole length, crosses the Behring Strait and follows the coastline of Asia until it joins up with the Europe-Asia line to the north of Australia. If the European line suggests particularly the Messina disaster of 1908, the Pacific line suggests San Francisco and Japan. Moreover, just as the South Pacific line follows a submerged mountain chain, so Japan owes the greater part of her earthquake troubles to the even more famous Tuscarora deep off the Pacific coast of the North Island. Similarly the fact that the southern half of the American continent experiences more earthquakes than the north can be directly connected with its greater ocean deeps.

A survey of about 160,000 earthquakes shows that 53 per cent. of all the world's earthquakes take place in the neighbourhood of the Europe-Asia line, and a further 38 per cent. along the Pacific's earthquake girdle. These figures include small earthquakes as well as big ones, but

even so there only remains a surplus of 9 per cent. for distribution over the whole of the rest of the earth's surface. There is certainly no doubt that earthquakes are connected with mountains.

The picture which we must have in mind takes as its starting-point the state of strain which must inevitably be left by the up-rearing of a big mountain chain. As its great mass settles down, the strain on the structure gradually increases, until breaking-point is somewhere reached. There is a slight slipping of two rock surfaces. The earth over a wide area is shaken to-and-fro, as the ends of a long stick vibrate when the stock is broken in the middle. So the strain is released, to be built up again over a period of years until breaking-point is again reached.

To that extent the general problem has been solved. It is known with more or less certainty why earthquakes take place and where they are most likely to take place. But with the practical problem of predicting the when and where of a particular earthquake, little progress has been made, in spite of its obvious importance in terms of human life. Some people have tried to blame the moon, which must certainly do its best to raise tides in the earth, just as it really does raise them in the sea. But when the sum of all the world's earthquakes is taken into account it is found that no explanation involving the moon is tenable.

Another theory is that earthquakes are preceded by electrical changes which will one day be detectable, and it has been claimed in Japan that the cat-fish can already do the job. The suggestion is that he is somehow aware

of the pre-existing state of strain, so that when his keeper taps on his tank he thinks that the earthquake has come—and dives suddenly for safety. Normally, being a sluggish creature, he apparently takes no special notice. It is not the sort of technique that sober-minded seismologists can be expected to accept with enthusiasm. They have a perfect right, moreover, to ask a number of questions—for example, how many minor earthquakes normally occur within the supposed range of the cat-fish and within the time allowed for the fulfilment of his "forecasts".

Yet, taken at their face value, these Japanese observations do suggest that the cat-fish is more often right than wrong—and there is certainly nothing improbable in the idea that other forms of life may be better able to appreciate the advance signs of an impending earthquake than are human beings. A dog can hear higher notes than we can, and there is good evidence that pheasants can hear distant gunfire when no sound can be detected by human ears. Nor, as a matter of fact, is there any suggestion that the supposed power of the cat-fish has any immediately sensational importance. It appears, if there is any truth behind these claims at all, that the cat-fish is equally sensitive to the smallest earth tremor, such as most mining districts often experience, and to the greatest earthquake. He is no good therefore as a serious forecaster, but he may yet point the way. If the cat-fish has any foreknowledge of earthquakes at all, there must be some physical change which scientific instruments should be able to detect. If not, well, the cat-fish is at least a stronger starter than the moon.

Thus, from the wearing away and deposition of rocks, from the slow tilting of great land masses, and from the short sharp movement of earthquakes, we can see from purely contemporary records, that the earth's crust is by no means fixed and stationary. The simplest deductions from the record of the rocks tell us that very much bigger movements must take place over long periods of years. Fifteen, thirty or a hundred feet above sea-level we may find raised "beaches". Thousands of feet higher are the fossilised remains of marine life which tell us that these rocks also were formed beneath the sea. And from the date of these marine deposits geologists can work out how the land-level has altered in particular districts in the course of millions of years.

Marine deposits even show by their nature and fossil content the rough depth of water in which they were laid down. It has been noticed, for example, that a modern river deposits the heaviest and most coarsely grained part of its silt near the mouth, the finer-grained mud being carried farther out to sea. It is only reasonable to suppose that ancient rivers behaved in the same way, and in fact a similar gradation can be traced in rock deposits which have long since been high and dry. Fossil forms tell the same story—more obviously. All sea-bottom life is closely dependent on the height of water above it and, by a study of modern forms, zoologists can get a very fair idea of the sort of depth in which different fossil beds were laid down. In these two ways old coastlines and the former distribution of land and sea can be to a large extent worked out.

At the time when the horse and the rhinoceros were just beginning to emerge, along with other mammals, from the welter of evolving forms, geologists find sea shells at what is now 16,000 feet above sea-level in the Himalaya and 10,000 feet above sea-level in the Alps. The great mountain masses of the modern world, including the Rockies, the Andes and the Caucasus, were still in their infancy, and but for the intervening record of fossils there would be few forms of life which we should to-day recognise. If the evolution of life has been a slow process, so also has the evolution of mountains.

It will not be surprising if we find considerable changes when we go back still farther, to the golden age of reptiles when eighty-feet dinosaurs splashed their heavy way through marshland and shallow water; and land, sea and air were alike populated by all those fantastic forms with which the modern world has lately become familiarised. Within this phase the "mesozoic" or Middle Age of life on the earth, we may take three flashlight pictures of our own country. They will be separated, naturally, by very long periods, although on the geological time-scale the intervals are in neither case so very great. In none of these pictures does England appear as an island. It was either a part of the Continent of Europe or beneath the sea.

In the first picture, in what geologists call the Middle Lias, London stands on the south-west coast of a peninsula which, jutting out from the mainland of the Continent, includes also the whole of what is now East Anglia. Cambridge also is part of the Continent, and Oxford

somewhere near its western seaboard. The whole of southern England, as well as the Midlands and the north, is beneath the sea. But Wales has its head above water. It represents the end of another peninsula, an eastern extension from a large land area sometimes called Atlantis. But although it bears this romantic name, there is no suggestion that it necessarily extends far enough out into the Atlantic to deserve the name of continent. It does, however, stretch across the greater part of Ireland and the southern part of the Irish Channel.

Our next picture, which geologists may recognise as the Wealden period at the close of the Jurassic, is even more strange. The land-level has risen generally, and the London peninsula, stretching out from the Continent, has joined hands with the Welsh peninsula, stretching out from Atlantis. There is solid land from Ireland to France. Yet in the middle of this great land area is an inland sea which is nearly three hundred miles in length. With its western shore beyond Weymouth, it covered practically the whole of what is now south-east England, as well as a large part of the English Channel and part of the French and Belgian coasts. Although England was part of the Continent both Dover and Calais were under water. A land journey from London to Paris would have been possible, but it would have involved a lengthy detour to either the east or west of the Wealden Lake.

In our third picture, from the time of the Lower Greensand, this particular cycle of change is nearly completed. London is again back on the south-west shore of a continental peninsula. The Wealden Lake has joined

forces on the one hand with the Atlantic Ocean and on the other with the North Sea. But the coast of Atlantis has not been driven so far back. Not only Wales but the whole of northern England remain within its confines. At the time of our first picture, it would have been possible to walk dry-shod from Dublin to Cardiff. Man, if such had existed, could now have walked on southwards to Plymouth and beyond, and east to Newcastle and out into what is now part of the North Sea. The changes, even within this small area of the earth's surface and within a relatively short period of geological time, have certainly been considerable. So far as present land areas are concerned they can be followed with more or less accuracy. There may be doubt, here and there, as to the exact boundary between sea and land. But the main outlines are certain, even if there is inevitably an element of speculation in any reconstruction which involves the past history of land now buried beneath the sea. The record of the rocks is no longer directly available.

Two main types of change have so far been mentioned, those represented by the uprearing of mountains and the rise and fall of continents. The theory which will account most satisfactorily for both of them is perhaps that originally put forward by the late Professor Joly of Dublin. It takes the radio-activity of the earth's crust as the motive power for both operations. Beneath both continents and oceans there is supposed to be a world-wide basaltic layer. This, Professor Joly suggested, must act as an automatically controlled radium furnace. Within it, as the radio-active break-down proceeds, heat gradually

accumulates. For millions of years there is no outward sign of change. Then, gradually, when sufficient heat is available, the whole mass becomes fluid. At the same time it expands and becomes lighter. The upreared continents sink down further into it beneath their own weight, as would icebergs in a lighter sea. Meantime the accumulated heat is released, partly through the oceans, partly through direct outpourings of basalt, and partly through the warming of the continental masses by conduction. Finally, both the basalt beneath and the continents above are again cooled down. The cooling of the basalt lifts the continents to their former level. Their own cooling wrinkles their surface into mountains, and one more cycle of change is completed, only to be repeated after a long interval when the heat reservoir has been replenished.

The calculations necessary to give precision to this most majestic rhythm have been made anew by Professor Arthur Holmes of Durham. For the basaltic layer immediately beneath the continents he finds that periods of maximum activity should be separated by intervals of about 25 to 40 million years. On the other hand the operation of a still deeper furnace would give a longer rhythm, one of 150 million years. There is much, admittedly, that is speculative in this picture. Its great advantage is that the double radium rhythm now postulated agrees very much more accurately with the record of the rocks than did Professor Joly's original theory. There are signs that, after a period of doubt, it is likely, for this reason, to enjoy a return to favour.

In all probability similar changes in the earth's crust are

to-day either in progress or in preparation. At the present time it appears that the earth is just recovering from an intensive period of mountain-building. More probably, recovery is not yet complete. Around the mountain girdle of the Pacific, there are signs of activity, particularly on its Asiatic side, and even within the present cycle of geological change nature may still have a few surprises in store.

Such tranquillity, in any case, is but temporary. The furnace, if Professor Joly was right, is again being prepared. Where holiday-makers now swim or indulge in surf-riding, others millions of years hence may be walking along a high ridge of smooth-turfed down. Miami and Palm Beach may be again submerged, as they have undoubtedly been in the past. Venice may lose its gondolas and Quito the distinction of being the highest capital in the world. The same forces that have worn away older mountains will as surely humble the Himalaya and the Rockies. New mountains will be born, in places which we cannot yet forecast, and new valleys dug to carry their rising rainfall away to the sea. But these are not the sort of changes which science can ever hope to follow. The tempo of nature is too slow. In comparison with the time-scale of geology, the life of man is as nothing, and the whole span of civilisation no more than a short episode. Here and there we may notice signs of change. Coast-lines are altering. The Sahara is advancing. Various African lakes are drying up. But of big land movements practically nothing is to be seen. There is, it is true, that slow tilting of Scandinavia which has been already men-

tioned. Other countries are no doubt moving, but the movements are not easy to interpret.

Everything changes and we too change with them, a German wrote more than a thousand years ago. There is no doubt about the extent to which we ourselves have changed, and that well within the period during which the earth's crust has been solid. Has there, then, been any larger change amid the continents of the world than those we have been considering? Is there any truth in the legend of the sunken continent of the Atlantic, in "Gondwanaland" in part lost beneath the Indian Ocean, or in the supposed "land bridge" that once connected South America with Africa? Are the continents fixed and immobile, apart from up-and-down movements such as have been already indicated? Or are even the continents adrift so that the whole surface of the world is literally in a state of flux?

It must be confessed that in these larger speculations the geologist is no longer master in his own house. Their main justification is the fact that biologists find it exceedingly difficult to account for the early spread of various forms of plant and animal life, except by supposing that the different continents were at some period united. So this rather curious position arises. The more conservative minded of geologists would be content to let the continents be. But the zoologist and the botanist are unwilling to do so. "Give us", they say, "a continental theory which will satisfy the requirements of our own science, and we will be content. We do not mind what sort of theory you put forward provided it gives us the

land connections that we want. But your idea that the continents have always been, in the main, as they now are, is wholly unpractical."

The difficulty is adequately indicated by the case of Australia. Here, in a continent which has presumably been long isolated, we have a unique fauna of pouched mammals, of which the kangaroo is the best known. They would be obviously unfitted to withstand competition from carnivores such as they would meet in any other part of the world; and from an evolutionary point of view they represent an early half-way house between the reptile and the fully developed mammal. The reptile lays its eggs and troubles no more about them. The mammal, with a womb developed for the purpose, carries its young within itself until they reach quite an advanced stage of development. Indeed, with the exception of human beings and apes, they are almost capable of taking care of themselves within a few days of being born. Between these extremes comes the marsupial. It has a womb in which its young can be housed for a relatively limited period. After that, when their original home has grown too small, they are relegated to the pouch. This interpretation is strengthened by the fact that the small pouched opossum, now confined to the American tropics, once flourished both in Europe and North America. The obvious conclusion is that the range of pouched mammals was once world-wide; and that their large-scale survival in Australia is due to the isolation of Australia from the rest of the world before their would-be competitors had arrived on the field.

Another problem, in which Australia is also concerned, is provided by the plant life which followed the end of the warm coal-forest period. The giant tree ferns which had then flourished gave way to smaller pointed ferns with compact leaves and greater power to resist cold. Their fossil remains, which are highly distinctive and quite unlike anything found on the earth to-day, come not only from Australia, but from South America, South Africa and India. Glacier markings tell also of an intensely cold ice age shared by each of these widely separated areas, but not by the rest of the world. Are we then to believe that there was at one time a land connection between them? This was the origin of Gondwanaland, the second of the suggested "lost continents" which have already been mentioned. It is supposed to have bridged the Indian and South Atlantic Oceans and to have incorporated Australia, the peninsula of India, Antarctica, part of Africa and South America—surely a tall order for even the most ambitious of continents.

So the plot thickens. Zoologists are equally convinced that there must once have been a close connection between the island of Madagascar and the Deccan of India; and there are signs also which point to a former connection between Europe and North America. Heather, for example, outside Europe, is found only in Newfoundland. The garden snail of South Germany and Britain is also found on the mainland of America—but only in Labrador, Newfoundland and the Eastern States of the U.S.A. It also inhabits both Iceland and Greenland in between.

Indeed, if the proposed Arctic Air Route is commercially developed, its passengers will to all intents and purposes be flying over a prehistoric snail route—although as an advertising slogan I am afraid the name may not be popular.

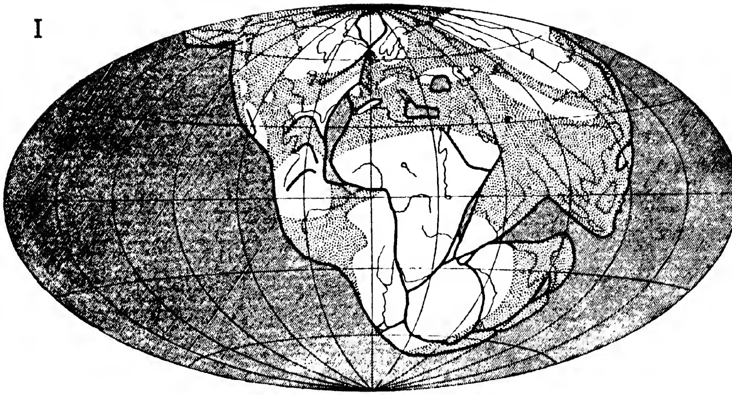
It is all a little difficult. There is, of course, nothing impossible in the idea that thousands of miles of ocean may once have been solid land, as in the case of Gondwana-land, but the more biologists elaborate their demands the more improbable do the necessary land bridges become. That is the real justification of the peculiarly attractive theory of "continental drift", put forward in recent years by Professor Alfred Wegener.

Professor Wegener believed that all the continents were once one, and that they are in a literal sense islands floating on a sea of less rigid rock beneath. Rather pleasingly his theory was originally based, as any schoolboy might have based it, on the neat way in which the bump on the right side of South America fits into the corresponding hollow on the left-hand side of Africa. This coincidence struck him, looking at a world atlas, in 1910, just as it must have struck many other people both before and since. So Professor Wegener was set wondering. He wondered if the foundations of the continents were really as solid as the superstructure which alone we know. He wondered if South America and Africa could ever have been one. But he did not wonder very seriously until he discovered a year later, what he had not known before, that there was strong biological evidence for supposing that Brazil and Africa were once connected.

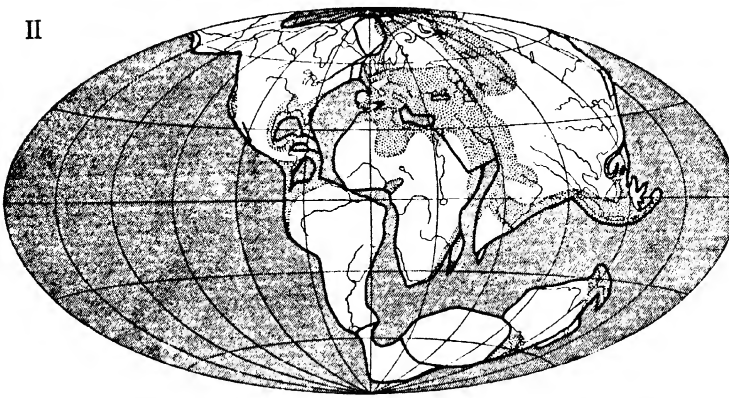
From that moment he never looked back. Just as Brazil would fit into the Gulf of Guinea on the African coast, so Greenland could be made to join up neatly with the west coast of Labrador and Baffin Island. As the accompanying map shows, Central America was justifiably widened in his reconstruction to include the Caribbean Sea and the West Indies. But even so, he was forced to leave a deep inland sea, as long as the Nile, between America and the top of Africa and Spain. Such difficulties must have only added to his enjoyment, for it is nct given to many to play at a jig-saw puzzle, with continents for pieces and a scientific theory as the prize. Once started on his bold experiment, the rest followed easily enough. The long line of the Red Sea naturally suggested a widening rift between Africa and Asia. Arabia, therefore, could be made African without difficulty. The Persian Gulf too he closed up, and swung round the whole of the rest of Asia, until the west coast of India lay along the African coast with its tip not far from Zanzibar. That ingenious manœuvre completed, he had only to fit on Australia, Antarctica and New Zealand to the south and the main picture was complete. In common with Professor Joly, Professor Wegener emphasised the instability of the continents, relative to the heavier rocks beneath; but whereas the supposed movement is vertical in the one case, it is horizontal in the other.

Where the various fractures took place, leading to the separation of the different continents, it would be natural to expect the throwing off of a splinter or two, in some

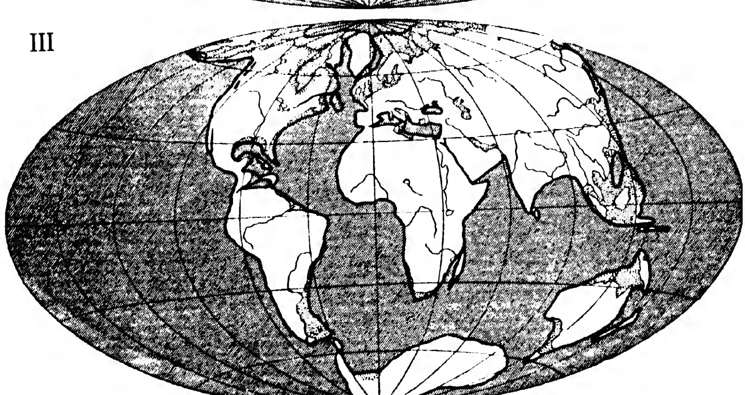
I



II



III



cases at a later date. For that possibility also Professor Wegener's world atlas makes provision. Newfoundland appears as a splinter drawn from the Bay of Biscay when Europe and North America parted company. So too Madagascar can be pictured as a by-product of the splitting away of India from Africa, while Iceland, to the east of Greenland, and a number of other islands are allotted a similar role. Naturally there are places where the fit is not perfect. Professor Wegener allowed that the continents have altered somewhat in shape since they left the family circle. But taken as a whole, and considered merely as a jig-saw puzzle, his theory is surprisingly, almost dangerously plausible.

It is also very convenient, for it provides biologists, at one stroke, with a wide variety of land bridges. Admittedly, the whole of the biological evidence already mentioned could equally well be used in support of the earlier "land bridge" suggestion. There are also difficulties in either case, so that the main difference is one of simplication. In place of a selection of *ad hoc* land bridges, we are given a single coherent theory. To that extent, and to that extent only, it is to be regarded on evolutionary grounds as more plausible.

There are, however, a number of other lines of evidence which can be used, in greater or less degree, to support the drift picture. Not the least intriguing is provided by an enterprising species of British Columbia plover which migrates for the winter to Hawaii—an unbroken ocean flight of nearly three thousand miles in either direction. Merely as a feat of endurance it is a surprising enough

performance. It also involves an accuracy of aerial navigation which, if it were not a fact, could only be described in our present state of knowledge as incredible. Certainly no human pilot, flying without instruments, could hope to do as well. But, when all allowance has been made for the uncanny instinct which apparently guides bird migration, another difficulty remains. How did the plovers find their way to Hawaii before their Hawaii-finding instinct had had time to develop? If we assume that the plovers took to migrating when Hawaii was very much nearer to the mainland, a large part of the difficulty is removed. The first generations of migrating plovers would then have had a relatively easy task; and as Hawaii moved imperceptibly away, those that followed would have plenty of time to adapt themselves to the longer journey.

There are, however, a number of places where it is possible to match up the rocks of different continents as well as their shapes. The rocks of the Hebrides have their counterpart in Canada, and the now humbled Appalachian mountains, which stretch from Alabama to the New England coast and must once have been as high as the Himalaya, provide an even more convincing link between the two sides of the North Atlantic. The same formation reappears in the Highlands of Scotland, in Devon and Cornwall, in Scandinavia and in the central plateau of France. Even the direction of these two early systems is roughly parallel. In addition, the extinct cold-living ferns and glacier markings, already mentioned, of the countries which now border the Indian and South

Atlantic oceans suggest that these countries were once one, and that their climate was very cold. Professor Wegener's theory brings them together, and the intense cold of their former climate can be explained on the supposition that they were at that time drifting across the South Pole.

So much may be given Professor Wegener. But, however attractive the theory of continental drift may appear, it would be idle to pretend that it can be regarded, for the present, as anything more than a theory. At almost every stage there are difficulties of detail. That perhaps is only to be expected. After all, it is a very long time since the supposed splitting of the primaeval continent, and it is inevitable that many of the clues should have got lost or become obscured. There is, moreover, the difficulty of finding any big enough force to make the continents move.

If there has been movement in the past, is there movement still to-day? Ultimately, perhaps within the next ten years, it should be possible to put the matter to the test. The key to this part of the problem is in the hands of surveyors. Professor Wegener himself suggested that, on the basis of his theory, the continents should still be drifting. In that case it should be possible to detect a contemporary movement. Iceland should be running away from Norway, Canada from Greenland, South America from South Africa. His procedure was to make a rough estimate of the periods at which the different fractures took place; and then, from the present positions of the land masses in question, to calculate the average rate at

which they have so far drifted apart. Unfortunately an interval which one authority will call ten million years, another will call twenty million, while a third, perhaps more wisely, will refuse to commit himself at all. But the fact remains that some sort of a guess can be made, and that the guess may be sufficiently accurate to give a rough idea of the sort of movement which we may look for.

The dating of the different fractures is determined, in part by the spread of evolutionary forms, in part by the geological history of the continents. South America is first supposed to have broken away from Africa, taking with it both Antarctica and Australia. Only after India had also broken away from Africa, and Australia and Antarctica in turn parted company with South America, is the North Atlantic bridge supposed to have been broken. This, on Professor Wegener's chronology, was a mere matter of fifty to one hundred thousand years ago. It is in the North Atlantic therefore that the supposed movement is likely to be greatest, assuming that it is still continuing at somewhere about the same rate as in the past. The necessary figures have been worked out by Professor Wegener, although as already indicated they must be taken as no more than the roughest of estimates. They can be most conveniently reproduced as an extract from one of his original tables, it being remembered that Sabine Island lies off the east coast of Greenland; that Bear Island is between Spitsbergen and Norway; and that Cape Farewell is the southernmost point of Greenland.

	Present distance apart in km.	Time of split in years	Annual movement in metres
Sabine I.—Bear I.	1070	50,000–100,000	21–11
Iceland—Norway	920	,, ,,	18–9
Cape Farewell—Scotland	1780	,, ,,	36–18
Cape Farewell—Labrador	790	,, ,,	16–8
Buenos Aires—Cape Town	6220	25,000,000	·2

In the last case at least the movement, small though it may appear, is considerably exaggerated by modern standards. It has merely been included to emphasise that it is in the North Atlantic, if anywhere, that the reality of Professor Wegener's theory will be proved. Perhaps it may seem strange that there should, in any of these cases, be any difficulty in detecting the supposed movement. We have talked of Scandinavia tilting from north to south at only four-tenths of an inch a year. Even the slow drifting apart of South America and Africa would involve a movement twenty times as great. The other examples (taking the lower figures in each case) range from 26 to 59 feet a year. It is quite true that such movements as these would be amply detectable. But the Scandinavian comparison is not quite fair. There the surveyors were dealing with a single land mass, and could use the accurate methods of land surveying. Where ocean gaps have to be bridged the problem is not so simple. As the movement is an east and west one, its measurement demands an accurate comparison of Greenwich and local times.

This has only become possible since the advent of wireless time signals, and so none of the older records, which should show relatively big movements, can be

admitted to the discussion. The first measurements based on the direct reception of European time were made in 1922 by Lieutenant Colonel Jensen when he determined the west longitude of North-east Greenland on the strength of time signals from the Nauen transmitter in Germany. Since then a number of other determinations have been made. But the verdict is, once again, "Not Proven".

Alfred Wegener lost his life in the great German expedition which under his leadership spent most of 1929, 1930 and 1931 in Greenland. It must be left to others to provide the evidence. So far as the present is concerned, there can be no half measures. Either the continents are moving—or they are not. But Professor Wegener's theory is mainly concerned with the past, and the mere absence of any contemporary movement would not in itself prove that the continents had never been adrift.

It is possible that the two pictures which have been put forward, that of the radium furnace and of continental drift, may be complementary. The radium furnace may provide the energy for mountain building and the rise of continents. It may also determine the times at which the continents begin to move. During periods when the basaltic layer is solid, it may be supposed, the continents remain fixed or nearly so; but when the furnace beneath has been reheated they once again become mobile. Then, they are literally floating in a molten sea, and a relatively small force will be required to set them moving. That was the compromise suggested by Professor Watts in his 1935 presidential address to the British Association.

It is a laudable attempt to take the best of both worlds, the world of the radium furnace and the world of drifting continents. There does not appear to be any real inconsistency between the two theories. The one will account for the up-and-down movement of continents, the other for their movement parallel to the earth's surface. Indeed the proposed combination has definite advantages. It appears that the ebb and flow of evolutionary forms over the surface of the earth is likely to prove too complicated to be fully explained on the basis of the single separation of the continents supposed by Professor Wegener. Now, however, a second mechanism has been introduced. With the repeated up-and-down movements of the radium theory there may, at times, be additional "land bridges" where to-day there is sea. Further, it will be less difficult to account for the drift movement of the continents if they are given something less solid through which to move.

If Professor Watts is right, the drift which carried New York from Europe, or Buenos Aires from South Africa, is now either greatly slowed down or wholly halted. In contemplating such stupendous changes, we may reflect that ours is a relatively peaceful age. We, and the most remote descendents that we can imagine, will only have to face the still continuing aftermath of the last great period of mountain building and continental movement. Only in the infinitely more remote future will the fires again be kindled.

This, perhaps, would be a gratifying conclusion. It would mean, moreover, that it would no longer be of importance for the credibility of the drift picture that any

contemporary movement should be detected. On the other hand, any sure and sustained movement of the great land masses in the required directions must be taken as direct confirmation of Professor Wegener's theory. Time alone will show whether there is any such movement to be detected. If the movement is there at all, there is no doubt that it will be measurable.

CHAPTER V

OUR WEATHER CAULDRON

"THE service will be run weather and other circumstances permitting." How often is not this printed notice, or its equivalent, seen beneath transport time-tables? It is a confession that is generally made in small type. But it is as necessary to-day as when Philip of Spain launched his Armada at England and was defeated by a gale. Local and coastal shipping services are liable to suspension in storm and to dislocation in fog. Snow can defeat both road and rail movement. Ice, at no exactly predictable date, puts an end to each season's trading whether through Russia's Arctic ports, or along Canada's new grain route to Europe via Hudson Bay. The weather is still our master, whether we like it or not. It is not without significance that the only consistently successful airship navigator has been the German, Commander Eckener. He modestly allows the weather to dictate his movements, and if some have criticised him for caution, he has had his reward. Nor is the farmer in better case. Any man who could predict the weather in each of the world's grain countries even one year ahead would die a millionaire. He would also (if he disclosed his information) earn the gratitude of farmers the world over. Even the ordinary man, planning his holiday, would be glad to know in advance if a fine summer was

in store, or whether July or August was to be the better month. There are few matters in which the gift of prophecy is more widely desired.

In proportion to its importance in everyday life man is remarkably ignorant about the weather. It has lately been computed that an inch of rain is roughly equivalent to twenty-two hours of summer sunshine. That is from the point of view of the energy which each represents. But who can tell whether the one or the other will be forthcoming a fortnight or a month hence? We may know that rain and sunshine are alike costly commodities. But we should have to possess a most unusual philosophy to accept a record-breaking downpour of eight or ten inches as a fair exchange for a fortnight or more of sunshine. We are told too of depressions advancing and retreating, of anticyclones that it is hoped will bring settled conditions. Yet the manner of their birth is still a matter for learned discussion, and meteorologists can give us only a few days' notice of their arrival. Of the more distant future we have as yet little knowledge at all.

With the problems of day-to-day forecasting we need not concern ourselves. The world's meteorological bureaux have a relatively good record in spite of all the abuse which is heaped on their heads. The real problems of meteorology are very much bigger. Not even the main rules of the world weather game are fully understood; much less can we forecast the run of the play for any time ahead in anything approaching detail. We know, naturally that it is likely to be colder in winter than in summer, and that some seasons of the year are wetter

than others. But to a large extent meteorologists can only play the part of bookie. "Three to one on good monsoon rains for India", they can call. "Two to one an extra cold winter for Alaska", "Five to one heavy rains in Northern Australia." Often, they will remain silent about the very places in which we are most interested; and when they can give six to one odds they feel they have done well. To-day that would no doubt be regarded as a good performance. To the meteorologists of the future it may seem less remarkable. The atmosphere, from which we get our weather, is a physical system obeying physical laws. Its working must in the long run prove predictable. The only difficulty is that the system is so vast.

"Pressure is high over Iceland and Scandinavia. An anticyclone is centred over the Azores." So much information, and indeed more besides, may be necessary for the proper understanding of one country's weather prospects for a couple of days ahead. Obviously the weather engine works on a big scale. Its working cannot be described in detail with any confidence, or there would be no unsolved problem. Only some of the chief working parts can be sketched in. Their very size and complexity give a more vivid impression of what the seasonal forecaster is up against than merely verbal emphasis.

The sun is, in the first place, the ultimate source of all weather—sunshine and warmth obviously, but also wind, rain and snow. Every form of weather represents energy, and the energy in every case comes from the sun. Alto-

gether the sun squanders a matter of £87,500 worth of light and heat a day on every square mile of the earth's surface. Not all of this, naturally, penetrates to ground-level in its original form. Part of the energy provided is straightway reflected back again into space, and part also is absorbed on its downwards journey through the atmosphere. Part again of what is absorbed is used to maintain the activity of the two wireless-reflecting layers in the atmosphere, which make the long distance reception of radio possible.

The weather uses of the sun's energy are equally varied. The ocean boiler-house, on which all land areas depend, must be kept working. Water is all the time being evaporated to descend later as rain upon the land. More immediately, rain is brought by the winds, and the winds take us back again to the sun as their energy source. Air movements are stimulated by temperature differences, for warm air is lighter than cold and tends to rise. And temperature differences are once again due to the sun's heat. But though the sun may provide the energy, the earth plays an important part in its disposal. Mountains modify air currents. More particularly they assist that rising of warm air into colder regions which is the precursor of rain. Land also, and the air above it, is more quickly warmed than is the surface of the sea, so that a summer bathe is always cool, although in winter it is colder inland than at the seaside. And to this we must add one more disturbing factor—Copernicus' discovery that the earth is spinning like a top.

So we come to the otherwise inexplicable behaviour of

anticyclones and depressions. These we cannot ignore, despite their mysterious names, for a large part of long-range forecasting, as well as of our daily weather, depends on pressure changes. Not that there is anything very mysterious about an anticyclone if it is remembered that a barometer is merely a weighing balance under another name. Instead of weighing a letter or a parcel against a series of standardised weights, it weighs the whole mass of air above it, right to the top of the atmosphere, against a column of mercury. An area of high pressure, otherwise an anticyclone, is therefore the outward and ground-level sign of a mountain of air up above. The mountain of air is heavy. So the mercury has to rise higher in the closed limb of the barometer to support its weight.

How should we expect such a mountain to behave? Air, after all, is not solid, and the mountain analogy is no more than an analogy. It could hardly come as a surprise if the mountain were to collapse. In fact we should naturally expect a continual outpouring of air from the base of the mountain. The mountain should, so to speak, spread out sideways. This is very much what happens, only the direction of the air movement is considerably altered by the spin of the earth. The effect is to give the outpouring a right-handed twist in the northern hemisphere and a left-handed twist in the southern. In northern latitudes the circulation of air round an anticyclone is therefore represented by an outwards and clockwise spiral. A depression or centre of low pressure, being the exact opposite of an anticyclone, is naturally accompanied by an inwards and anticlockwise movement.

Here then is a picture, admittedly a little old-fashioned, of two of the chief players in our world weather game. It is old-fashioned because modern meteorologists tend to regard a depression as a symptom and not a first cause. They think, to a large extent, in terms of great air streams; and talk of "Polar fronts" and "cold fronts" and "warm fronts" as the boundaries between different types of air streams. The modern picture is often of great practical value in day-to-day forecasting. It also gives a ready idea of the large movements which go to make up our purely local weather, whether in London, New York or San Francisco. But depressions and anticyclones remain real enough, whatever their cause; and this brief reference to the modernistic picture will have served its purpose if we remember that even the general theory of world weather is very far from being fully established.

The old-fashioned depression and anticyclone can fortunately give us quite a good enough picture of the scale on which we are working. An anticyclone, viewed at ground-level, it may be again emphasised, is a sort of air fountain. Air is always streaming outwards from its centre. Similarly a depression is an air "swallow". At ground-level, air is always being drawn into it. Yet there are, on the earth's surface, a number of great and more or less permanent depressions and anticyclones. In the North Atlantic there is the Icelandic "low" and the Azores "high". Antarctica is a region of permanent low pressure, and in the oceans to its north there are three corresponding "highs"—one in the Indian ocean, one in the South Atlantic and one in the South Pacific. Nor is

the list even now complete, although it is probably long enough to be suggestive. Each of these air mountains or depressions is always giving away or receiving air at ground-level. Yet the supply is never exhausted. Clearly the ground-level picture is incomplete. If the air mountain is collapsing at its base, it must be perpetually replenished at higher levels. There must be a permanent circulation system, operating in one direction at ground level, and in the opposite direction higher up.

Finally, before we pass to man's somewhat puny attempts at long-range forecasting, we may take one further lesson in humility. A barometer, it has already been said, is nothing more than a weighing balance. It is therefore possible, by comparing barometer readings in a large number of places, to make an estimate of the total weight of air over the northern hemisphere under winter and summer conditions. This is one of Sir Napier Shaw's weather hobbies. He finds that between the months of January and July, the northern hemisphere loses ten million million tons of air—an annually repeated present to its sister hemisphere of the south. And between July and January the southern hemisphere hands the same amount of air back again. It is a transaction calculated to make meteorologists feel more than a little small. From one point of view all our storms and droughts, our heat waves and cold spells, are but insignificant by-products of this annual air transfer. The transfer may be slightly changed, or carried out in a slightly different way from usual—and the weather of continents is affected.

Do not St Swithin and all the country omens derived

from sows, birds and berries begin to look a little ridiculous? Is it likely that a rook, building its nest high, has any more profound knowledge than we of world air movements? Has the "Thanksgiving" goose his own weather stations in Alaska and the Antipodes to warn him of impending change? This is not to say that all country weather omens are so much nonsense. There is some ground, for example, for the shepherd's optimistic belief in the value of "a red sky at night", and a number of other signs have a day-to-day significance as an aid to weather forecasting. Sailors, also, were aware that the appearance of thread-like clouds in the north-west might herald bad weather long before it was realised that this particular portent often marked the front edge of an advancing depression.

A probable explanation of the supposed power of birds and animals to show the weather a long way ahead is the prosaic fact that good and bad seasons have a tendency to occur in sequences of like weather. Thus it might be supposed that a fine summer will encourage birds to nest high during the following season; and, if this summer also is fine, it will appear that they have done wisely. But the tendency is certainly not definite enough to have any forecasting value. Nor can human forgetfulness be omitted from the reckoning. Old Tom's successful prediction of a hard winter from his observations of birds, berries or what you please, is going to be remembered by his neighbours long after his other, and possibly equally numerous, failures have been forgotten. The average country weather prophet would be much less widely

esteemed if systematic records were kept of his successes and failures.

It is to be regretted that many of the most famous weather omens, either prove frankly absurd on examination or are self-contradictory. Both criticisms apply to the famous old English rhyme, "When the ash is out before the oak, then we may expect a choke (heavy rain). When the oak is out before the ash, then we may expect a splash (only a little rain)." This is the sort of tradition that everyone would like to see justified. But there are several difficulties. One is that the ash, in the ordinary course of events, always precedes the oak. This may perhaps correspond with the known fact that there are plenty of wet days in most English seasons, and in this sense there is no gainsaying the truth of the omen. On the other hand, there happens also in the north of England to be a variety of oak which as regularly precedes the ash, while there is also an alternative, if less widely accepted, version of the rhyme which exactly reverses the significance of the augury.

There remain two methods by which man has attempted, on a more or less scientific basis, to probe the more distant future. He has attempted to trace weather cycles, and he has attempted also to find connections between the present weather in one part of the world, and future weather elsewhere. The quest for weather cycles is natural enough and has been pursued with varying success for many centuries. There is nothing ridiculous about the idea that our weather may tend to repeat itself at regular intervals, except possibly that this

particular solution looks a little too easy. The great Francis Bacon, Lord Verulam, three hundred years ago placed on record the suggestion that there was a thirty-five-year cycle, now known as the Bruckner cycle, in European weather, and in every generation there have been meteorologists ready to spend time and labour on looking for "repeat" signals. The Bruckner cycle, for example, has been meticulously traced not merely in connection with London's rainfall records, the barometric pressure at Paris and the temperature in Berlin and Stockholm; but also in the excellence of the wine season in wine-producing countries and the severity of the winter.

But a weather cycle is more interesting when there is something to account for it, and so in modern times especially there has been particular interest in the so-called sunspot cycle. It has already been emphasised that the sun is the source of all our weather, and it is a natural tribute to his power to suppose that changes on the sun's surface may produce corresponding changes on the earth. The sun, at any rate, plays his part well. There is a more or less regular cycle of solar activity of 11·4 years length. The most obvious sign of this change, although not necessarily its cause, is provided by sunspots. These are dark spots on the sun's surface which are interpreted by astronomers as great vortices, generally large enough to swallow up the whole of the earth with a good bit to spare. We do not know either how sunspots are formed, or why there are more sunspots in some years than in others. But the main facts are beyond dispute. At

least since 1826, and so far as the evidence goes for very much longer, there has been a regular up-and-down variation in solar activity. Sometimes the interval between successive periods of greatest quiet has been as short as ten years, and sometimes as long as thirteen. But on the whole the sun has stuck remarkably closely to its 11·4 years' cycle.

It is also certain that the sun's cycle has definite and well-marked effects on happenings on the earth. Shorter wave-lengths can, for example, be used for Transatlantic radio reception when there are many sunspots than when there are few; and both the frequency of magnetic storms and of the beautiful Northern Lights appear to be governed by the sunspot cycle. There is no doubt therefore of the sun's power. The only question is to what extent the sunspot cycle can legitimately be connected with world weather. The most convincing proof that there is some such connection is provided by the water-level on Lake Victoria Nyanza in Central Africa. Here weather and sunspots seem to move in perfect step, the highest level of the lake corresponding with sunspot maxima and *vice versa*. It also seems that there are, on the average, more thunderstorms over the world as a whole, when there are most sunspots, and that the connection is most clearly marked in Siberia, the tropical Pacific and the West Indies. Dr Charles G. Abbot, the secretary of the Smithsonian Institute, has also attempted to make use of a twenty-three-year cycle, otherwise a double sunspot cycle. One of his examples of recurrence of weather after this interval of time is drawn from Central

India. At first sight it certainly looks suggestive. There, between the years 1865 and 1870, three winters of heavy rainfall were separated by unusual droughts, and twenty-three years later the same weather appeared. On the basis of this coincidence Dr Abbot has predicted that there will be similar droughts between 1942 and 1948. Similarly, on the strength of Nebraska weather records, he has predicted a dry period in central United States between 1939 and 1948.

It may be that Dr Abbot's forecasts will be fulfilled. But all that is generally agreed is that changes on the sun do have some effect on the weather. However interesting some of the supposed connections may be, it would be idle to pretend they had so far proved of any appreciable value to the weather forecaster. The sun seems to have a much more direct influence on the upper layers of the atmosphere, in which the Aurora shines and radio waves are reflected, than on the lower layers from which our weather comes. The sun's cycle is not itself of definitely fixed length, and its connection with world weather happenings appears to be unreliable. Much the same criticism applies to other supposed cycles, whether by themselves or used in combination. In some cases the cycle may appear to be real, but its influence is so small as to be useless for practical purposes. In other cases what appears to be a regular rhythm will follow a regular course over a considerable period of years, only to disappear suddenly and without warning when any meteorologist is rash enough to base a forecast upon it.

There is fortunately a different story when we turn

instead to look for weather relationships between different parts of the world. The weather symphony may be one of great complexity, but it is not necessary to understand the whole in order to have some knowledge of what different groups of players are doing. Watching the movements of players in Greenland and Antarctica, in South America and Malay, we may learn something at least of the technique of orchestration. Here and there a complete sequence will emerge, the same melody being first rendered by one player, taken up in harmony by another, and repeated, perhaps with variations by a third. A violin sequence in Buenos Aires and Port Darwin may prove to be followed, four times out of five, by the roll of the big drum in Java. Players in Winnipeg and Edmonton may appear to take their cue from others as far apart as central Africa and Honolulu. The weather of the world may be irregular in detail, at least over large areas. But, viewed as a whole, we can at least glimpse the beginning of order in eccentricities which at first sight seem unconnected.

The first studies in weather harmonies of this type date back to the work of the Swedish meteorologist, Hildebrandsen, at the end of last century. Hildebrandsen put forward the theory of what he called "centres of action". These were to be places which, in varying degree, should play the part of conductors to the complete orchestra. If the normal rhythm was interrupted by syncopation in one of them, he supposed, then other areas would begin to play to the same tune, a month, six months or a year hence. His centres of action were from another point of view places where "advance shows" were held to indicate

coming weather fashions in other parts of the world. In his original theory they were represented by a number of more or less enduring areas of high and low pressure—in the North Atlantic, for example, the notorious Icelandic "low" and the Azores "high".

The picture which he had in mind was a gigantic back-and-forth surge of air between pairs of such areas. If the North Atlantic is regarded as an isolated system, then an intensification of the Azores "high" will be automatically followed by a corresponding intensification of the Icelandic "low". A rising barometer at the Azores implies that the mass of air over that region is being piled up higher than before. New air has therefore flowed in and, if the Azores-Iceland can be regarded as an isolated system, it can only have come from the latter region. The barometer in Iceland should therefore show a corresponding fall. Naturally there is an element of artificiality in any such simple picture. But for all that the North Atlantic link-up is closer than is generally realised, even by many meteorologists. It is extraordinary, for example, how closely the temperature in such widely separated places as Stornaway, to the extreme north-west of the British Isles, and Charleston on the south-east coast of the United States, in each case keeps in step with the crucial pressure difference between the Azores and Iceland. It may be disrespectful to liken the North Atlantic to a weather concertina. But the picture is, to a large extent, true. Altogether three such concertinas are now recognised. There is another in the North Pacific, operating between the high pressure area off the United

States and Canada, and the Aleutian islands between Alaska and Eastern Siberia. A third concertina operates between the South Pacific and the land areas round the Indian Ocean. There may also be a fourth between the Argentine and Antarctica, but this is not yet certain.

But although Hildebrandsen's general picture still holds good, it cannot explain everything. For example, the winter temperature of the south-west corner of Africa is "controlled" to a quite extraordinary extent by a cold ocean current flowing from between Antarctica and the southern tip of South America. Curiously enough, this current takes just about a year to make the journey, so that a winter temperature forecast for that corner of South Africa could be prepared with considerable confidence from records taken exactly a year earlier at Ano Nuevo. Elsewhere "control" seems sometimes to be exercised by areas of high rainfall. In this category we may include the attempted use of the Himalayan snowfall as an aid to forecasting, as well as that of the Nile flood, the latter being a convenient summary of the rainfall over a large area of Central Africa. In still other cases it is merely known that control of some kind is exercised, the problem of how and why being left for future solution.

Meteorologists the world over have attempted to trace past and present weather connections of this kind. Japan, Java, South Africa and Germany have each played their part. But by general consent the most important progress has come from India. The amount of time and trouble which people are prepared to spend on the weather inevitably depends on the importance of the

weather to them. In England, for example, there is a great deal of interest in day-to-day weather, relatively little in seasonal forecasting—which is just as well because English weather is notoriously difficult to forecast. In India, on the other hand, the position is exactly reversed. Day-to-day weather is relatively stable. But a good monsoon means the difference between famine and security for hundreds of thousands. So it is that the Indian Meteorological Office has for many years devoted a considerable proportion of its energies to attempts to forecast the all-important June to September rains. At one time it is true the standard of reliability was such that it had to be officially decreed that the forecasts prepared should be regarded as secret and confidential until the time for their fulfilment (or the reverse) was safely over. There was too much danger that, while meteorologists might be promising India bread, nature might be preparing a particularly arid stone.

In the early days forecasts were simply, but inaccurately, based on the Himalayan snows. Gradually it was realised that India's weather problems were not hers alone. So the process of expansion began; until Sir Gilbert Walker, now a professor of London University, has extended his "Indian" weather studies to cover practically the whole world. One result is a new and moderately reliable formula for the prediction of monsoon rains. It involves knowledge of previous weather conditions in South America, the Cape, Dutch Harbour in Alaska, Java, Zanzibar and Southern Rhodesia—a list sufficiently varied and lengthy to satisfy the most internationally minded.

Altogether Sir Gilbert examined the part played by no less than seventeen "centres of action" over as long a period of years as records were available. It was a titanic undertaking, and it is certainly impossible to say that further connections of the same kind do not remain to be discovered. To express the labour involved is not easy. He had, in the first place to collect, quarter by quarter, the selected weather statistics for each area for as many years as possible. But this was only the raw material for a strictly mathematical inquiry. His main task was to work out to what extent, if at all, the weather at each centre was connected with the past, present and future weather at each of the other sixteen centres. For every possible pairing of his seventeen centres he had five comparisons to make. Weather at centre A might depend on that of either one or two quarters earlier at station B, in which case the connection would be of use to the A forecaster and not to the man concerned with B. Or the connection might be contemporary; or the weather at B might lag one or two quarters behind that at A. The forecasting value of the connection would then be reversed.

It might be found for example that, three times out of five, when the barometer rose at A to a higher level than usual, it was abnormally wet at B six months later. That would not constitute a very reliable basis for forecasting, but so far as it went it would be better than nothing. In any case not less than four or five areas would be found to foreshow coming weather at the required station. There would be that number of different omens, some more

convincing and others less, perhaps not even consistent. The task of combining the different omens is again one for the statistician. So, as statistics are apt to be depressing we may content ourselves for the moment with taking a rapid run round the world, and seeing how some of these centres of action play their parts. Although the reasons are by no means always understood it will be obvious that the players' activities are in most cases strictly seasonal. For three months or so, they are prepared to conduct the orchestra. Then, for a large part of the year they hand over the baton to someone else. Like well-behaved instrumentalists, they take the time instead of setting it.

The Indian peninsula, for example, is most active during the monsoon. Just as weather happenings in widely separated parts of the world affect the monsoon, so do variations in the monsoon exert a profound influence in other countries. Indeed, to the sorrow of Indian meteorologists, it is easier to predict on the strength of the monsoon than to predict the strength of the monsoon itself. For good or ill the monsoon rains of India exert a 66 per cent. influence two quarters later in Alaska; a 62 per cent. influence in South-east Australia and a 52 per cent. influence at the Cape. The Indian peasant who has seen his livelihood destroyed by a poor season could at least reflect, if his education permitted, that his sufferings were of world-wide significance.

In the following or Christmas quarter North-west India takes up the tale. Its rising or falling barometer determines the general run of weather in Samoa three months later with something approaching certainty.

South America is also particularly active at this time. Represented by Buenos Aires, Cordoba and Santiago, it makes itself felt, on the one hand in Port Darwin, and on the other at the Cape. South America being below the equator, this is an example of summer-time activity. Siberia, the coldest place in the world, is most active during the winter. If the barometer is high there at that time, it will probably be low in San Francisco six months later. Then from June to August it is the turn of Honolulu. Once again San Francisco is affected. But this time the two centres move in the same direction. If it is "high" in Honolulu, it will be high also in San Francisco, and *vice versa.* The time interval in this case is only a matter of three months, and the "control" is not very vigorous. Honolulu is only in charge to the extent of 38 per cent. A good American may perhaps feel that this is quite a sufficient degree of domination. But for forecasting purposes there is nothing like having one's weather thoroughly controlled by someone else. Unfortunately the English-speaking peoples are not, in general, well-favoured in this respect.

So the tale goes on, first one country taking control and then another, but more often several at once. If the weather symphony has a master conductor, his whereabouts have not yet been found. Or perhaps we should state the problem a little differently. We know that the sun controls our main weather rhythms. But it is the syncopations, the variations from one season to another, that chiefly interest us for forecasting purposes. And, though we may guess that these also originate in the sun,

we cannot tell how closely the different players follow his lead. Indeed we are not even sure in what way the baton is wielded. It is only by putting together all the known connections with past weather in different parts of the world that a seasonal forecast is obtained. This is not a simple matter, because it by no means follows that all the different probabilities are independent.

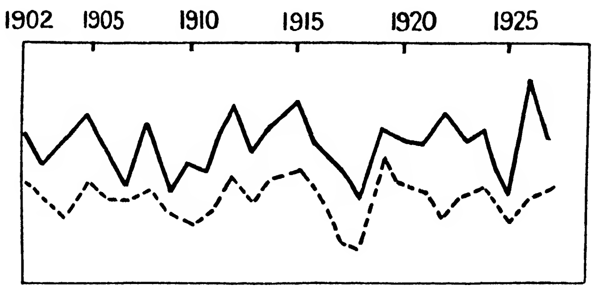
The difficulty may be illustrated from the peculiar case of my friend, Mr Smith. I may know that there is no more than a one-tenth chance (nine to one against) that he will go out on a wet night. I may also be prepared to venture the same odds against him turning out when he is in a bad temper. But if Mr Smith's good humour is entirely governed by the weather, it will take me no farther to know that the night is wet *and* Mr Smith in a bad temper. But in practice the connection is not likely to be so clear-cut. Mr Smith may have quarrelled with his wife, lost money on the Stock Exchange, or broken his collar stud. If his bad temper is due to any of these causes, it may be presumed that he will be definitely less likely to go out than if it was merely raining.

It is so also with weather harmonies. Each new relationship adds something to the plausibility of the final forecast. But not all the relationships carry full weight. I may know, for example, that the conditions in Australia and South Africa both exert some control over the coming weather in South America. But my weather tables may also show that conditions in Australia and South Africa are themselves connected. The same difficulty will arise in the case of each of the other omens.

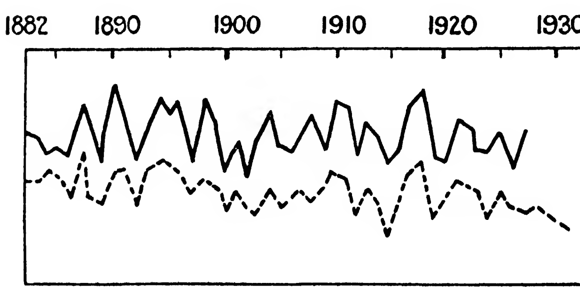
Each omen will add something of value, but it will not be at once obvious how much. A forecasting formula will be necessary. Moreover the formula will have to be most carefully devised if each omen is to be given its proper weight.

Sir Gilbert Walker's Indian formula has already been mentioned. Many others have been worked out, both by him and other meteorologists. For us they are of interest only as showing how closely the weather of different countries is linked up; and the degree of reliability which can be expected from this type of forecast. There is one, for example, for South-west Canada (Winnipeg, Calgary, Edmonton, etc.), which is no doubt also applicable to adjoining areas in the United States. Warm weather in this area tends to be preceded by low pressure in Honolulu, high pressure in North Australia, a scanty Indian monsoon, a low Nile flood and a high temperature at Madras. Taken together these various and geographically scattered omens represent a 73 per cent. probability. For the North-west Canadian winter a similar formula is applicable, except that conditions at Zanzibar have also to be taken into account. The accompanying figure shows how closely the average winter temperature at Dawson has followed the calculated curve over a twenty-seven year period. If the agreement were exact, the two curves would be strictly parallel. Although this is not the case the general correspondence is certainly remarkable. The second set of curves applies to a large area of northern Australia. Similar methods have also been applied in other parts of the world.

The two sets of curves here illustrated bring out very clearly both the powers and the limitations of the method so far as it is at present available. The first impression is one of the excellence of the general "fit". There is certainly room for congratulation. The main peaks and



Winter Temperature at Dawson, N.W. Canada.
Actual ———; Calculated - - - - -.



Similar Curves for Northern Australia.

valleys of the calculated curve are reproduced in the "actual" curve. But even here there are exceptions. Towards the right-hand side of the North-west Canada diagram there is an obvious case of a valley on the calculated curve corresponding with a peak on the actual curve. Such accidents represent an admitted weakness of

the prediction formula. Only some 80 per cent. of the controlling factors being covered, it is but to be expected that the formula should sometimes break down. There is also the difficulty that minor and unexplained variations may completely upset any forecast in which only a small departure from the normal is indicated. A really cold or a really warm winter may be successfully foreshadowed. But anything between is probably better left alone. For practical purposes this is not so serious a drawback. It is the extremes, whether of drought, rainfall or cold, of which farmers and others want to be forewarned. But even on these it seems that the seasonal forecaster is doomed to make bad mistakes from time to time. Sir Gilbert's own criterion is that no forecast should ever be issued unless there is at least a four to one chance that it will be fulfilled. It follows that, with a formula covering 80 per cent. of the controlling factors, it should on the average be possible to issue a forecast every other year. If only 70 per cent. of the factors are covered, then forecasts with the same standard of probability could be issued in two out of every five years. This may not sound very impressive. On the other hand, the mere absence of a forecast would indicate that no very marked departure from the normal was expected.

What view will the world take of seasonal forecasting on such a basis as this? To what extent does one mistake nullify years of successful effort? If farmers have once been told that a bumper season is in prospect, when in fact drought stares them in the face, will they have any confidence whatever in future forecasts? Will they re-

cognise that with four to one forecasts, issued every other year, there is likely to be a bad mistake once every ten years? What of the effect on the world's commodity markets? These are questions as much for statesmen and agricultural organisations as for meteorologists. Sir Gilbert would frankly recognise the position by calling his forecasts "foreshadowings". They cannot be made or broken by a name. The practical issue is whether practical men will take them seriously.

Time, to a certain extent, is working on the side of the weather forecaster. The mere accumulation of records enables world interconnections, such as they are, to be established with greater certainty. Moreover the number of weather statistics which can be examined for such long period connections is almost limitless. It is true that difficulties may still remain even in the most favourable cases, and that for many countries, including England, no seasonal forecasts worth having may be possible. But to a certain extent there will be improvement. A larger proportion of the "controlling factors" will, in each case be covered, and the margin of uncertainty progressively reduced. That will be something, although not necessarily enough to satisfy all critics. Is there any ground for a more favourable "further outlook"?

The two problems, of the theoretical world-picture and of practical forecasting, are inevitably closely related. From the brief sketch which has been given it will have been obvious that there are big gaps in our knowledge of world weather. It is not merely that the data have not yet been reduced to order. They are very far from

being complete. Weather reports from large ocean areas are either inadequate or wholly lacking. Except for two "International Polar Years", separated by a fifty years' interval, practically no knowledge is available regarding the course of weather in the Arctic. Yet Arctic weather makes an important contribution to that of both England and North America. How often do we not hear of a "break through" of Polar air? Even less is known of Antarctic weather, for whereas the North Pole is ringed with land, the Antarctic continent is surrounded by a vast expanse of ocean.

All this ignorance applies to happenings at ground level. Yet the air which blows about our houses is but a minute proportion of that great mass whose weight forces up the mercury in our barometers. How high must we go up to have full knowledge? This air that we breathe may once have been at a great height above the earth. The delicate and thread-like clouds, known to meteorologists as cirrus and emphatically a part of the weather system, float at a height of 25,000 to 35,000 feet, say five or six miles above the ground. There is reason to believe that the latter figure represents about the limit of height which need be taken into practical consideration. Above that there is no more cloud and no more variation in local temperature, although there must naturally be day and night, and winter and summer, changes. But there is no weather in the variable sense in which we understand the term at ground level.

Yet six miles is quite a thick enough slice of the atmosphere to hope to keep under constant observation. More

than one balloonist, it is true, has passed the ten miles level; and *ballons sondes*, carrying instruments but no human observers, have reached heights of twenty miles and more. But human ascents have been few and far between, and *ballons sondes* have only been sent up, with any approach to regularity, from quite a limited number of centres. They are, moreover, a relatively expensive way of getting information, for instruments as well as balloons are liable to get lost. It is hardly conceivable that anything approaching a world network of *ballons sondes* stations should ever be set up, unless indeed the requirements of aviation made such a course essential. It is, perhaps, to high altitude flying that the meteorologist may look for the next important advance in world weather recording. Whether by their own observations, or through observations made on their behalf, the aerial navigators of the future may be expected to make an important contribution to our weather picture.

There is nothing magical about our atmosphere, complicated as it is. It is but a physical system of air and water vapour, affected alike by the sun's radiation and the daily rotation of the earth. Our weather, which seems to us so capricious, must presumably be explicable and amenable to scientific law. If we had complete knowledge of world weather, at all heights, at the moment, we should in theory be able to calculate that which is to come. We should probably also want to know how the sun's radiation was changing in accordance with the sunspot cycle. But in theory at least the possibility would be there.

This is a great deal to ask. Long before that stage had been reached weather information would have begun to accumulate which could in time be used for working out new inter-relationships of the kind already described. Conditions of wind, temperature and air moisture would be available, month by month and season by season, far up into the atmosphere. At present we have only the bare information, yielded by the barometer, that above a region of high pressure there is raised a mountain of air. Then, knowledge would be more detailed. Sir Gilbert Walker or his successors would be able to find new relationships connecting conditions five miles above Tokyo with those at ground level at San Francisco or New York six months later. Greenland, or other Arctic stations, may give the clue to England's variable seasons. The missing "control factors" will be run, if not to earth, at least to their home in the sky or amid Polar ice and snow.

In some cases also the sun's control may prove significant. For such areas the perfect forecast formula will take account of periodicities as well as of world interconnections, and the two lines of approach which we have been discussing will have been brought together. Already, in a few instances, there is a movement in this direction. But it certainly looks as if the newer method is the more hopeful. Just because it is more complicated, it can take account of more complex variations—and as we have seen the world weather system is nothing if not complicated. Such knowledge as we possess has been won laboriously and after many disappointments. Beside the vast ocean of the air it appears very little. If there is still, at the

best, a note of uncertainty in the forecaster's voice as he shouts the odds, it is at least permissible to hope that the problem will not for ever defy solution. Achievement may be small, but the promise and the hope are for all to see.

CHAPTER VI

MESSAGES FROM SPACE

IF from the universe around us we subtract every one of the countless millions of stars which astronomers have discovered, every scrap of matter which can be recognised in a telescope, what is there left? Just nothingness would be the obvious answer, a vast area devoid of both matter and distinguishing marks of all kinds, save that an imaginary traveller would find himself slowly moving towards some stars and away from others. Yet we are always receiving messages from outer space, and these messages suggest that space is neither so dull nor so featureless as might be supposed.

So-called cosmic rays, many times more penetrating than the most powerful X-rays, are all the time beating down on us from space, passing with ease through brick and mortar, slipping unbeknownst through our bodies, and even reaching down to the bottom of the deepest lakes. The earth too has its daily bombardment of meteors, not comparable fortunately with the great Siberian meteorite of 1908 which would have been big enough to have wiped out New York or London at a blow, but bright enough to be observed and counted by astronomers, even if the great majority pass unnoticed by most of us.

From the study of our atmosphere also, we can learn a

little of the space on which it abuts. Although the atmosphere has a clearly marked boundary at ground-level, it has no sharply defined upper limit. It merely fades imperceptibly into the "not quite emptiness" we call space. So it is that from the records brought back by high-altitude sounding balloons, and from the travel of sound at great heights above the earth, we may be able to learn something of space itself. The telescopes of astronomers, more prolific of information about the stars, have also something to tell us. Space may be nearer to being a complete vacuum than the best human engineers can produce, yet it is still far from being empty. Most intriguing of all perhaps is the wide range of methods by which our knowledge, such as it is, is obtained. Not merely can we never get at space, there is nothing with which we can even compare it. It is something entirely outside the range of earthly experience. Yet from clues gathered here and there, some sort of a picture can be put together. Probably in no other field of enquiry is the scientist so much of a detective, so little assisted by "circumstantial evidence". From beginning to end it is a matter of ingenious deduction.

We may begin by accepting Sir Arthur Eddington's admission that, although astronomers had long preferred to regard space as empty, there was no real reason to believe that this was the case. It was merely a matter of convenience in that the present appearance and probable histories of stars could be most easily classified on the supposition that there was no appreciable "atmosphere" between them. Such an atmosphere, if there were much of it, would affect both the apparent brightness of stars,

and their speeds and directions of movement. The mere possibility of an interstellar atmosphere was quite sufficient to upset the best-planned calculations—if the possibility had been accepted. So it was that astronomers preferred to forget what they did not want to know. They knew that, although each of the nebulae contained a host of stars, part of its brightness was due to matter which had not yet condensed, possibly never would condense, into stars. They knew also that, although these great clouds of matter were thickest in the middle, it was quite impossible to say where they began or ended. There was here at least a strong hint that the nebulae which could be seen were but an exaggeration of a more tenuous cosmic cloud which could not be seen. But this was no more than a hint, and there was certainly no suggestion that the cosmic cloud could be detected—much less analysed from a distance.

Perhaps it is most natural to begin with the top of our own atmosphere, the earthward fringe of whatever may fill surrounding space. It will tell us nothing directly about what is to be found in space, but it will at least provide a pointer in another direction. The snow-line of mountains, the intense cold of Mount Everest, and the freezing of water vapour on the wings of aeroplanes flying at great heights all combine to suggest that the further up we go, the colder it will be. But a sufficiently thick slice of the atmosphere has been directly explored with balloons to show that this is only true up to a point. The Soviet "stratosphere" balloon, manned with human observers, reached a height of nearly twelve miles before meeting

disaster on the downward journey. Professor Piccard, and his successor, Max Cosyns, as well as Commander Settle in the United States, have all reached or passed the ten miles limit, the latter by a substantial margin—and sounding balloons, carrying automatic recording apparatus have penetrated to very much higher levels. One which was sent up from Padua is believed to have reached a height of twenty-three and a half miles, while a Hamburg balloon attained a height of only one mile less. It was, however, as far back as 1898 that the French scientist, Tessereinc de Bort, discovered that, although the thermometer fell steadily up to a height of six or seven miles, it remained steady above that height. In temperate latitudes this steady temperature is somewhere in the neighbourhood of -60 degrees Fahrenheit, although strangely enough it is considerably colder above the equator.

Thirty-five years later, in the summer of 1934, a series of Belgian ascents established the further fact that above the region of steady temperature the tendency is towards greater warmth. But, again rather unexpectedly, the most striking evidence of this reversal is provided by records, taken in Germany, England and other countries of the long-distance travel of sound-waves. Europe had plenty of opportunity to study the subject during the last war, the essential fact being that there may be a zone of silence, within which the sound does not penetrate, although it is clearly audible on either side. Samuel Pepys, ever curious in such matters, had noticed this effect in the Dutch war of 1666, and had written in

his diary that "this makes room for a great dispute in philosophy, how we should hear it and they not, the same wind that brought it to us being the same that should bring it to them".

The proposed "dispute" attracted no interest until the present century, nor is there at the present time any serious disagreement on the subject. The clue to the mystery is to be found in the fact that the travel of sound-waves is dependent on the temperature of the air in which they travel. The warmer the air, the more quickly one "packet" of air hands on the energy of the sound to the next, and the more rapidly the sound wave travels. So it is that, if sound is travelling outwards from an explosion at different levels, the part of the wave nearer the ground will continually be gaining on that higher up. The front of the wave is therefore tilted progressively upwards as the advancing sound reaches colder regions of the atmosphere. In fact the sound is bent upwards. This goes on until it has reached the region of steady temperature. Thenceforward there is nothing for some further distance to alter its course. At this stage, it may be repeated, the sound is still travelling sharply upwards and away from the earth's surface. What, then, is going to bring it down again?

The only possible answer is a rise in temperature at still greater heights, such as is already suggested by the records brought down by sounding balloons. The upper part of the wave, travelling in warmer air, will then gain on the lower part and the sound will be bent down again. Such a rise in temperature is, now at any rate, taken

for granted. The theory, which has everything to commend it, at the same time gives an explanation of the existence of "zones of silence", and has enabled scientists to make estimates of both the greatest height reached by the sound waves and the temperature at that height. The height limit appears to be about thirty miles, and the temperature in the neighbourhood of 130 degrees. That takes us a good way up, both in height and warmth—far enough in each case to suggest that immediately away from the earth's atmosphere it is not likely to be intensely cold.

Meteors, which will make another and more interesting appearance in the story later, point the same lesson. These small visitors from outer space, generally no bigger than a pin's head, flame suddenly into visibility at a height of about seventy miles, and in most cases have burnt out their brief existence by the time they have dropped a further twenty miles towards the earth. Their heating up, which is purely a surface effect in the case of larger meteors, is due to the friction of the atmosphere. Naturally there will not be sufficient friction unless the air through which they are passing is sufficiently dense to offer substantial resistance to their movement. Calculation shows that, on the older picture of the atmosphere, with temperature dropping steadily, meteors should not become seriously overheated until they have progressed considerably further into the atmosphere. Only a layer of warm, buoyant air, capable of supporting a greater mass of air up above, can explain their observed behaviour. So the three lines of evidence are met. Sounding bal-

loons, the travel of sound waves, and the flaming course of meteors all tell the same story. The upper layers of the atmosphere are very much warmer than we might have expected—and, if the top of our atmosphere is hardly a fair sample of the cosmic cloud, it will at least not come wholly as a surprise if we find later that it may be warmer still farther away.

The first discovery pointing to the real existence of the cosmic cloud was made as far back as 1904 by the German astronomer, Dr Johannes Hartmann, then an assistant at Leipzig Observatory. His instrument was the telescope, and his method the light analysis of stars, on which practically all our knowledge of stellar constitution is ultimately based. Light analysis is in itself a complete subject. In the case of the stars, it tells astronomers how hot particular stars are, what their atmospheres are made of, if what appears to be one star is really two close together, and whether particular stars are moving towards or away from our sun. At the opposite end of the scale it is equally informative about the happenings in the atomic world. In fact the analysis of light is the scientific weapon which, above all others, should have gladdened the heart of Sherlock Holmes. The investigator who uses it has no need to be present in person to obtain the evidence he needs. He can use photographic plates instead. Nor need the criminal be near at hand. The only limitation is that sufficient light must be available. How far it has come is, in the ordinary way, immaterial.

The main principles of this deductive technique are relatively simple. They are, in fact, based upon the rain-

bow, which to the eye of a scientist represents nothing more romantic than the spreading out of the sun's light, wave-length by wave-length, so that each colour is separately visible. Light, when it has been sorted out in this orderly way, is known as a spectrum; and the instrument which does the sorting as a spectroscope, if the eye is doing the observing, and a spectrograph if the records are being taken on a photographic plate. Astronomers naturally prefer the spectrograph, because if a photographic plate is given a sufficiently long exposure it will show markings which are very much fainter than the human eye can see.

One more digression is necessary in order to explain that there are two quite different kinds of spectra, and that this distinction is of great help to astronomers. White-hot solids, like the incandescent wire of an electric lamp, give continuous spectra; that is, all wave-lengths are represented although the energy of the radiation is not equally distributed between them. Laboratory experiments show that the part of the spectrum that is brightest, representing the most energy, provides a ready-made indication of the temperature at which the light is being produced. As the sun and the stars have white-hot spectra that is the way in which their temperatures are taken, although such estimates naturally only refer to the layers of the star from which the light is coming. But for our present purpose, it is only necessary to remember that the stars are continuously radiating light, and for that matter heat and ultra-violet waves, of all wave-lengths.

Gases, on the other hand, produce an entirely different type of spectrum. Instead of a continuous range of

wave-lengths, the whole energy of radiation is concentrated into a large number of sharply defined wave-lengths. Each kind of atom gives its own elaborate pattern of lines, so that merely by looking at a gas spectrograph the physicist can say with certainty which chemical elements are represented. Moreover it so happens, and this is where astronomers benefit, that gases absorb light selectively as well as emitting selectivity. A relatively cool gas, too cool to give out any light, absorbs exactly the same pattern of wave-lengths as it would itself give out if it were hot enough to do so. It robs any radiation which may pass through it of just those wave-lengths which it wants. The light which astronomers receive in their telescopes therefore bears the impress of whatever relatively cool gases it may have passed through on its way. It is as if a detective examining a case of valuables after a robbery were to say, "That was Bill Sykes. He's only taken the silver spoons".

The star's original radiation consists of a continuous range of wave-lengths. So what astronomers see is a continuous spectrum marked by a series of dark lines where light has been stolen from it on the way. The continuous spectrum indicates the temperature of the star; the dark lines carry (among other things) the pattern of the sun's atmosphere and of the earth's, as well as that of the cosmic cloud through which by far the longest stretch of the journey has been.

But the scientific detective has still to decide which pattern belongs to which—and at this point it is necessary to refer again to an effect which has already been mentioned

in discussing the "expanding universe". This is the fact that the wave-length of any kind of light is slightly increased or diminished according as the source of light is moving towards or away from the observer. The effect, it was explained, is analogous to the sudden drop in the pitch of an engine's whistle as a train passes a watcher by the line. It provides the means by which the rate of expansion of the universe is measured. It also provides the proof that there is a cosmic cloud which is in no way connected with the movement of either the stars or of the earth.

Dr Hartmann's discovery came from his observation of the movements of a particular "double star" in Orion's belt. It often happens that what appears to the naked eye, or even in a telescope, to be a single star, is really two stars circling round one another, just as do the head and the tail of a dog when he chases his own tail. In that case the pattern of each star's movement is shown in the light spectrum and astronomers know that, whatever appearances may suggest, they are dealing with two stars instead of one. It is so even if one of the two stars is too faint for its light to be received. Although there is no direct sign of the faint star's existence, the bright star can be watched circling, and it can only be deduced that it is circling about another star. Such was the double star in Orion's belt; and, when Dr Hartmann noticed two lines in its spectrum which did not share in the known movement of the bright star, his first thought was no doubt that he had at long last discovered its fainter twin. But unfortunately these lines did not share in the presumed motion of the fainter star

either. Nor could they come from the earth's atmosphere, for the position of the mysterious lines showed that their source was definitely moving with respect to the earth. There was no doubt, however, that they corresponded with the chemical element calcium, which on the earth is most commonly found in the form of chalk.

Somewhere, between the radiant surface of the star and Dr Hartmann's telescope, there had to be a cloud of calcium. It was not in the star's atmosphere, and it was not in the earth's. Rather daringly, on the strength of this one observation, Dr Hartmann put forward the explanation that his mysterious calcium cloud was one manifestation of what we have already been discussing as the cosmic cloud, a faint outspreading of matter which links star to star and knows no other boundaries but space itself. Naturally he had many critics. But as the years have gone by, his views have won acceptance, largely through the work of Dr V. M. Slipher at Flagstaff Observatory, Arizona and Dr J. S. Plaskett, at the Dominion Observatory, British Columbia. The same lines have been detected in the spectra of other stars. It has also been found that their strength is roughly proportional to the distance of the stars, as it should be if they have been picked up on the long journey from star to telescope. In addition a line corresponding with the element sodium (of common salt) has also been detected.

That, for the present, is all that can be said with real certainty about the constitution of the cosmic cloud, apart from the rather obvious fact that it must be exceedingly tenuous. No doubt it contains other chemical elements

as well, for there are plenty of reasons why not all those kinds of atoms which may be present in it should readily make themselves known to us. In particular there is some reason for believing that the cosmic cloud contains both oxygen and nitrogen, so that it consists to some extent of ordinary air. The elements of chalk, salt and ordinary air—it is quite a homely cloud, even if it is also rather remote. It is also very far from being insignificant. Although its density must be inconceivably less than the highest vacuum which human engineers can produce, it has been calculated that the cosmic cloud probably represents about one-third of all the matter in each island universe of stars. Yet until recently its very existence was not generally accepted, and even now all estimates of its density can only be regarded as tentative in the extreme. The figure quoted is that favoured by Sir Arthur Eddington—but he would be the last person to suggest that it was in any way final. Such as it is, it represents a density of one atom per thimbleful of cosmic cloud. Figures such as this tend to be meaningless—but, for the sake of a comparison, a thimbleful of ordinary air contains atoms to the number of fifty million million million.

It also appears that the cosmic cloud may, by earthly standards, be remarkably hot. This is partly the result of such an extreme rarity of atoms; partly also the result of the modern picture of the exchange of energy between matter and radiation. It might seem at first sight that, far away from any star, the cosmic cloud must soon lose any heat energy which it possessed. But it must be remembered that even in the remotest regions of space a

certain amount of heat is always passing from the stars—and that there is not very much of the cosmic cloud to keep warm. Moreover the time when a gas tends to lose heat is when its particles collide, which in this case will not be very often. Although the cosmic cloud has little chance to get warm, it has equally little chance to cool down.

Sir Arthur has, however, pointed out[1] that there is another factor operating which should tend to raise the temperature of the cloud. An atom, and this is the basis of the photo-electric cell of television, may absorb a complete "packet" of light energy, a high-speed electron of equivalent energy being shot out from it. In due course the electron will be recaptured, either by the same atom or by another, and the momentum of the electron transferred to the new partnership. The ultimate result of this throwing out of electrons by light is therefore to increase the average speed of movement of the atoms—which is another way of saying, to raise the temperature of the cloud. On the other hand, the faster the atoms are moving around, the more likely they will be to collide with one another and therefore to lose the heat which they have acquired. Between the two processes there must be an equilibrium, and Sir Arthur Eddington has calculated that this is reached at a temperature of about 27,000 degrees Fahrenheit. This is a long way from the intense cold originally postulated, and there are not many people who would like to commit themselves definitely as to whether Sir Arthur is right or wrong.

[1] *New Pathways in Science*, Cambridge University Press.

Such are the main facts about the cosmic cloud, so far as they are known. There is no doubt, at any rate, about its existence, or that it is extremely finely spread. It seems also that, like the human appendix, it should be regarded as a relic of an earlier stage in the evolution of the universe. The cosmic cloud must once have been, not merely universal, but all that there was of matter. Then, out of the eddies of primaeval chaos, the stars were born. Part of the cosmic cloud condensed into solid matter. The rest, which astronomers now see faintly in their spectrographs, represents the leavings of creation. It may be that creation, in this sense, is still proceeding; that the stars in their majestic course are slowly sweeping up the leavings, gathering to themselves such parts of the cosmic cloud as come their way by the force of their own attraction. On the other hand, it also seems probable that the stars may be losing part of their atmospheres to the cloud. Sooner or later the two processes must balance, and it may be that the cosmic cloud, as it now is, is eternal.

So far we have managed to populate space with quite a number of different inhabitants, although none of them are of more than atomic size. Harvard University has lately added some others, which are a little more solid. Meteors have already been mentioned as providing an indication of the temperature high up in the earth's atmosphere. Some of them, it now seems probable, are genuine visitors from outer space. They come to us, at any rate from outside the solar system. The clue in this case is their speed. Even allowing for the earth's speed

of eighteen miles a second round the sun, forty-four miles a second is the greatest possible speed at which a meteor, travelling in a closed orbit round the sun, could hit the earth. Any higher speed can only mean that it has come from outside. From a survey undertaken by Dr Opik in Arizona it appears that the arrival speed is in some cases as great as 130 miles a second. It has been proved that more than twenty million meteors must strike the earth every day; that an appreciable portion of them must come from outside the solar system; and that they come from all directions equally. Here, then, are our more solid inhabitants of space—small enough, certainly, by astronomical standards, but infinitely large compared with the lonely atoms of the cosmic cloud.

Once again, we are completely in the dark as to how these meteors came into being. It is possible that they were thrown off, and are still being thrown off, by the stars. Once out in space, and away from the gravitational pull of the stars which gave them birth, they might wander for an eternity before hitting the earth or any other obstacle. Their life must in any case be very curious—almost completely uneventful, until a sudden flaming, as they enter the atmosphere of some star or planet, brings them death. Incidentally, anything so solid as a meteor, must pass the greater part of its existence in an extremity of cold, even if Sir Arthur Eddington is right in suggesting that the cosmic cloud is unexpectedly hot. There would not be enough of the cosmic cloud to keep even the smallest of meteors warm, and any heat which it might itself possess would speedily be lost by radiation. The meteor

population of space must be very nearly as cold as it is possible to be. So should we be, if we were rash enough to venture into that uncharted land.

But by far the most mysterious of all messages from space are cosmic rays, more penetrating than the most penetrating rays from radium, yet coming from no one knows where. They have been welcomed on their first arrival in our atmosphere with balloons. They have been pursued to the bottom of snow-fed lakes. They have been studied on mountain tops and on plains, in high latitudes and low. In a perfectly ordinary laboratory, they have provided scientists with a hitherto unknown type of atomic particle, the positive electron. Their penetrating power has been measured and found to vary considerably, although always very great. Almost as many scientific papers have been written about them as about the atom itself. But when all has been done, it has not yet proved possible to say even what cosmic rays are, much less how they are produced, or where they come from in the first instance.

The discovery of cosmic rays was, from one point of view, a necessary result of the study of radium. But there was nothing romantic about the preliminaries. It was known that, in theory, perfectly dry air should be a perfect insulator of electricity—that is, it should not be possible to produce a flow of electricity through it. It was known also that various types of radiation, including X-rays and the radiation from radium, had the power of increasing the conductivity of air through which they passed. Moreover, in the case of radio-active materials,

measurements of this increase in conductivity provide the standard method of estimating the strength of the radiation produced. Attention was therefore early directed to the small residual conductivity which normal air always possesses. It was natural to suspect that some form of radiation was responsible for this also. This belief was strengthened by the discovery that the unwanted leakage of electricity across air could be reduced by lead screening, and the preliminary suggestion was made that the unknown rays came from radio-active material in the earth's crust. But it was not long before it was proved that this conveniently simple explanation would not work.

Records made at the top of the Eiffel Tower in Paris first suggested that the offending radiation could not come from the earth. Then in a series of balloon flights, an Austrian, V. H. Hess, made the discovery that this unexplained leakage of electricity increased as his recording instrument was taken higher up into the atmosphere. The radiation, whatever it was, was presumably beating down on the earth from above. This conclusion was speedily confirmed as a result of a more accurate series of records made by a German, W. Kolhörster—and the new rays were conveniently dubbed "cosmic" although there was no proof at the time that their origin was in space. To-day, however, there is no doubt about what are, after all, the two most important facts. Cosmic rays are real, for they can be photographed; and they come from outside the solar system, for their numbers show no variation with either light or darkness or with the earth's changing

seasons[1]. The only observed variation, a very slight one with sidereal time, is best interpreted as indicating that some at least of the rays which scientists photograph individually in their laboratories have come from outside the whole vast system of stars of which the sun is one member. For hundreds of thousands of years they must have travelled on their monotonous way, with the speed of light or very nearly. Within less than a hundredth of a second they have completed the traverse of our atmosphere. At the same speed they pierce, unheeding, the roof and walls of some laboratory. And, at the end, an automatically clicking camera may show them literally "knocking spots" from the air particles of the scientist's recording chamber. It is no wonder that such trouble has been taken to try to solve the riddle of their origin.

The first and most serious difficulty about cosmic rays is that no one has yet devised a method of taking records anywhere near the top of our atmosphere. The height record for cosmic ray measurements is held at the time of writing by Professor Regener of Stuttgart with a pilot balloon ascent of seventeen and a half miles. But, relatively speaking, that is not a very long way up. Radio scientists talk of wireless waves being reflected at heights of a hundred or more miles above the earth, and there is no reason to suppose that even that is anywhere near the

[1] That they do not originate within the atmosphere is shown by (1) the great energies required for their production, (2) the analysis of balloon records, (3) the variation with sidereal time, below, and (4) various effects, described later in this chapter, which can only be explained in terms of the influence of the earth's magnetism on the approaching rays.

top. The highest Auroral lights come from 600 miles up, more than thirty times as high as the level reached by Professor Regener's balloon. It can be deduced with certainty that some cosmic rays come from outside the atmosphere. But it by no means follows that all the cosmic rays recorded at ground level, or even at a height of seventeen and a half miles, originated in that way. Indeed it has long been realised that the primary rays, arriving from outer space, might produce secondary rays within the atmosphere by their impact on air particles. The production of secondary rays can in fact be photographed in any ground-level laboratory which happens to possess suitable equipment. Such photographs sometimes show what can only be described as a "shower" of cosmic rays, all obviously springing from the same point—and all presumably caused by the impact of a single, more powerful, primary ray. But even if no photographs of this kind had been obtained, scientists would still have no choice but to believe that many of the rays received at ground-level were only "secondaries". Balloon records tell the same story, but in a less direct way. The observed manner in which the intensity of the rays falls off, as they penetrate farther into the atmosphere, cannot be explained as a matter of absorption by the air alone. On the other hand it is perfectly consistent with the idea that while some rays are being absorbed, secondary rays are also being produced. It is therefore no simple matter to tell what cosmic rays are like when they first reach the earth.

The original suggestion was that cosmic rays are of the

same kind as X-rays, only of shorter wave-length and greater energy and penetrating power. In that case they would be members of the already extensive "electromagnetic" family, which beginning with the long waves of wireless, stretches down through the infra-red waves of fog-piercing photography and the waves of ordinary light to ultra-violet waves, X-rays and the even shorter "gamma" rays of radium. All these kinds of waves, however apparently different, are of the same nature. They differ only in wave-length, and in the conditions under which they may be produced, reflected, absorbed and so on.

The exciting thing about cosmic rays, according to this picture, was the enormous energies which must be necessary to produce them. It is fairly generally known that high electrical voltages are used in the production of X-rays. This is the explanation of the heavily sheathed cables employed in all X-ray units. They are thus sheathed to guard against any possibility that either patient or doctor might be unintentionally electrocuted. Very much higher voltages, and still more elaborate precautions are necessary in those few institutions in which X-rays equivalent to the "gamma" rays of radium are produced. And, if we go down still further in the wave-length scale, the necessary expenditure of energy is proportionately increased. In the case of cosmic rays there is no adequate source for their energy but the building up or destruction of matter itself. Here is one way in which cosmic rays may, in a real sense, bring with them messages from outer space.

It may seem strange to talk of the building up of matter as a possible source of energy. But it is not at all extraordinary if the idea that mass is a form of energy is accepted as a starting-point. It is all a question of the weights of different kinds of atom. We know that if a heavier atom was formed by the union of a number of hydrogen atoms, it would be slightly lighter than the combined weight of the atoms from which it was made. The equivalent amount of radiation would then be available for distribution as radiation. This radiation would, in a real sense, represent the birth-cry of the more complicated atom. By contrast, the complete annihilation of a hydrogen atom would release a very much larger amount of energy. Its whole mass would have been transformed into radiation instead of only a fraction of its mass. Both the building up of atoms, and their annihilation, will therefore serve as possible sources of energy—but the annihilation of matter is the more potent source.

The idea that matter may all the time be being recreated in what was once regarded as empty space is certainly attractive. It was first put forward by the American scientist, Professor R. A. Millikan. If it is true it will involve a radical revision of the generally accepted belief that the universe is "running down", by which is meant a slow but inevitable movement to a dead level of uniformity, at which no further change is possible. The universe, as it has previously been known, may be running down. But, according to Professor Millikan, the motive machinery is being rewound continuously out in space. It may be so, although Professor Millikan's re-

creation process will not provide sufficient energy to account for the most penetrating rays of which records have so far been obtained—in particular for some of the cosmic ray "showers" which are apparently produced by the impact of a single primary ray. If recreation in space is accepted as the origin of some cosmic rays, the annihilation of matter must be accepted as the origin of others.

In his search, in association with Professor Millikan, for abnormal conditions in which annihilation waves might be produced, Dr Zwicky of Pasadena hit upon the peculiar star explosions represented by the appearance of novae. These are stars which, having for untold years been either very faint or entirely unknown, flame suddenly into unwonted brilliance. Within a few days the brightness of such a star may increase to one hundred thousand times its former level, while it is believed that the star may at the same time expand to one hundred times its original size. With such violent changes going on it would certainly not be surprising if a certain amount of matter got annihilated. But whether there are a sufficient number of novae to provide any measurable proportion of cosmic rays is another matter.

Dr Zwicky's theory was put forward in 1934. In December of the same year a nova made its appearance. There were indications of a slight increase in cosmic ray activity. But the records, made in a number of different laboratories at the time, proved inconclusive. Nor, in any case, would such explosive stars be called upon to provide the entire cosmic ray supply of space. According to Professor Millikan's picture, "recreation in space"

would still be retained as the explanation of all but the most penetrating waves.

There is, however, an alternative picture. Whatever may be the nature of primary cosmic rays, there is no doubt that a large proportion of the cosmic rays received at ground-level are not waves at all, but electrically charged particles. These are the type of cosmic rays which get their photographs taken. They may at the same time be "analysed", in the sense that the bending of their path by a powerful magnet both provides a measure of their speed and tells the observer whether they are positively or negatively charged. Merely taken by themselves, these ground-level records give little information about the original cosmic rays. The particles observed might equally well be produced by the impact of these on the upper atmosphere. Such records do, however, suggest what has so far proved the most hopeful method of tackling the main problem.

The earth itself is a still more powerful magnet and, if the primary rays consist of charged particles, their course as they approach it should be considerably deflected. The mathematical analysis involved is exceedingly complicated. But fortunately some of the main conclusions can be quite simply stated. Their interest is that they apply only to charged particles and not to any form of wave which, like those of sunlight, should pursue a very nearly direct course through the atmosphere. In general, the tendency of any charged particle approaching the earth is to follow some form of spiral towards one or other magnetic pole. The faster the particle, however, the greater will be its im-

munity from magnetic deflection, and the wider the range of places on the earth's surface to which it can penetrate. Particles of very low energy will be confined to the two poles, only particles of the highest energy being able to reach the equator. There should thus, at first sight, be a continuous increase in the number of cosmic rays from the magnetic poles to the equator.

At any point on the earth's surface, however, the particles must have a certain minimum energy if they are to get through the earth's atmosphere, irrespective of latitude, without being absorbed. Further calculation shows that any particle which possesses this minimum energy will automatically be able to reach any point between the poles and a latitude of 45 to 50 degrees. Within this range of latitude there should be no variation at ground-level, although at greater heights above the earth the concentration of relatively feeble particles near the poles should make itself felt. In any case there should be a falling off in the number of cosmic rays recorded at ground-level between latitudes of 45 to 50 degrees and the equator.

The latest research has been largely directed to clearing up these two points. The reality of the predicted ground-level variation was shown once and for all as the result of an ambitious survey organised from the universities of Chicago and Denver during the years 1932 and 1933. Ten different expeditions were sent out, with their headquarters as far north as Spitzbergen and as far south as New Zealand. Their combined records, taken at eighty-one different stations, showed that there were on the average 14 per cent. more cosmic rays in Polar and tem-

perate regions than at the equator. This figure may be subject to revision, but there seems no doubt at any rate that the effect measured is a real one.

Professor Millikan has not travelled so far, but he has flown high. He has been responsible for the records taken in a series of high-altitude aeroplane flights, ranging from Cormorant Lake in Northern Manitoba to Peru. Heights of 22,000 feet were reached in his aeroplane survey, while further records were obtained in the United States balloon ascent made by Lieutenant-Commander T. G. W. Settle and Major Chester le Fordney, when a height of eleven miles was reached. Here also measurement agrees with theory. The excess of cosmic rays at high altitudes at Spokane, Washington (54° N.), or Cormorant Lake (63° N.), as compared with Peru or Panama near the equator proved to be as much as 40 per cent. This agrees with the conclusion that, at sufficient heights above the earth, low-energy particles, too feeble to penetrate to ground-level, should be increasingly in evidence the greater the distance from the equator. So this ironical situation has arisen. Professor Millikan, apostle of the "recreation in space" theory, has himself provided part of the evidence in favour of the opposition.

There is another piece of evidence which is not without interest. According to theory, the tendency should be for positively charged particles to arrive from the west, and for negatively charged particles to arrive from the east. Actually it is found, at a height of some thousand metres above the equator, that the westerly intensity is about 16 per cent. greater than the easterly. This is evi-

dence that a larger proportion of primary rays consists of positive than of negative electrons. Positive electrons are a newly discovered type of atomic particle which will be discussed in the chapter on "Nature's Building Bricks". All that matters for the moment is that they are minutely small and electrically charged. The disproportion, however, is evidence in favour of the particle theory in general; for, if the primary rays consisted entirely of waves, there should be no east-and-west difference at all. On this point all three lines of evidence are in agreement. However much may be doubtful, it at least seems certain that an appreciable proportion of primary rays are not waves but electrically charged particles. On the other hand, Professor Millikan still maintains that there are other rays which are genuine waves, and that both "recreation in space" and "annihilation" are necessary to account for them.

So the battle rages, if such a friendly difference of opinion may be so described. Nowadays the positive electron is fashionable, and it is fashionable also to assert that at least the majority of cosmic rays consist of positive electrons. Perhaps part of the attraction may lie in the suggestion that an appreciable part of the population of outer space should consist of a type of particle which, until a few years ago, was entirely unknown. But it is at least possible that both sides may be right. There was a somewhat similar dispute about the sun and radio a few years ago. It was known that the wireless-reflecting layers of the upper atmosphere were kept active by the sun. There were day-and-night variations, and winter-

and-summer variations, and even long-period variations in tune with the eleven-year cycle of solar activity. But one school held that the sun's control was exercised through ultra-violet light, and another school pinned their faith to a stream of electrically charged particles. To test their different beliefs a number of expeditions were sent to take radio records, first during a total eclipse of the sun, and then up into the Arctic where the effect of the earth's magnetism should be most strongly shown. The first test favoured the ultra-violet light theory, but not conclusively. The second test proved conclusively that both sides were right.

Finally, before taking farewell of these most mysterious rays, it may be well to see how the different theories that we have been discussing affect our ideas about space. Cosmic rays, in the first place, arrive from all directions equally. The east-west effect, already mentioned, is a purely local effect due to the earth's magnetism. It is therefore reasonable to suppose that, whether waves, particles or both, cosmic rays fill the whole of space. They may, as has indeed been suggested, have no further connection with space than that they are always travelling through it. They may have been produced at the creation and have voyaged through space ever since—until they hit the earth. But, in so far as cosmic rays consist of charged particles, there is no reason to suppose that they have always possessed the great energies which many of them now show. Professor E. A. Milne of Oxford University has proved with charming simplicity that any free particle, at large in space, must in course of time be ac-

celerated up to a speed approaching that of light by the gravitational pull of the rest of the universe. It will then begin to slow down again, so that at any particular time and in any particular part of space, there should be a supply of particles of all possible speeds. Here also we have a suggestion that the clock is being perpetually rewound—although not in so dramatic a manner as Professor Millikan postulates. In either case cosmic rays would, in a real sense, have their origin in space.

In an unending stream they arrive from space—yet it is no ordinary stream for they come from all directions. They pass daily through our bodies and must, one would think, remembering the parallels of radium and X-Rays, have some effect on them. It has even been suggestea that they may play some part in promoting the evolution of new species. Yet we are still not sure either what they are, or how they originate. The problem is certainly fascinating. As ever, the chief hope lies in more, and more extended observations.

CHAPTER VII

THE ORIGIN OF MAN

IN 1633 Galileo formally agreed to abjure, curse and detest that heretical depravity which had led him to suggest that the earth moved round the sun. Two hundred and twenty-four years later Professor Baden Powell of Oxford University drew upon his head the public censure of a learned Scottish divine by irreligiously suggesting that a human skull, found during the making of a railway through the Cotswold Hills, should be accounted of earlier date than Adam. Another two years, and Charles Darwin published *The Origin of Species*, thereby evoking such a storm of ecclesiastical indignation as had not been equalled since the Reformation. Has human evolution even now been proved? Had man an ape ancestor? Along what lines did he advance to manhood?

To ask such questions at the present day may seem more than a little extraordinary. From Darwin's day to this no single effective criticism of the main theory of evolution has ever been put forward. Evolution in general is proved, so far as any theory which seeks to explain the far-distant past can ever be logically proved. The main sequence of living forms has been worked out—from fish to amphibia, now chiefly represented by the much abused toad; from amphibia to the ever-popular dinosaur; until towards the close of the great age of reptiles mammals are

beginning to appear. In a large number of cases the ancestry of forms now living has been explored in circumstantial detail. To mention two familiar examples only, the history of the elephant and the horse, with the latter's intriguing progress towards one-toed walking, has been followed through countless thousands of years from the recovered remains of their prehistoric ancestors.

At the same time the slow breakdown of radio-active minerals within the earth's rocks, in accordance with known laws, has enabled geologists to reckon time in hundreds of millions of years instead of the thousands of Biblical chronology. The time needed for the long process of evolution has been won; and the working of the process so far uncovered in such a variety of cases, that no open-minded critic could fail to be convinced. Moreover, the strength of the evidence is cumulative and quite independent of such questions as are still debated by biologists—questions of the mechanism of evolution and of the detailed descent of particular species and groups of species[1].

Yet the ancestry of man himself has so far proved irrecoverable. Some time, somewhere there must have been a first man. That man must have had an ancestry, in part at least in common with that of the great apes—the orang outang, the gorilla and the chimpanzee. So much is generally recognised. It would be impossible, even if

[1] More fundamentally, the fact that any evolutionary theory must account for degeneration as well as for progress, that there seems to have been a force, call it what you will, driving some forms to self-extinction through the development of useless and even harmful adaptations, as well as other forms along the upward lines on which attention tended at first to be concentrated.

there were no other evidence, for anyone approaching the problem impartially to decide that man was the one exception to the evolutionary process. Yet we do not know in what country the first man walked and hunted, or the date of his beginning within so much as a million years. Still less do we know the line of his descent in anything approaching detail. If anything, we know rather less than we thought we did, say, thirty years ago. Yet in the intervening period many new remains of early man have been discovered, and both the field of search and the number and technical equipment of anthropologists enormously extended.

So much being unknown it may be well to emphasise the general grounds for believing in human as well as in animal evolution. There is, first and foremost, the difficulty of believing that man is the one exception to the evolutionary process. More direct evidence is, however, obtainable—and of two different kinds, both familiar in the study of animal evolution. One is of the type generally known as anatomical, although it includes the study of all kinds of physical resemblances between related species. The deduction is that species which have a large number of characteristics in common have a common, or at least a similar, ancestry; and the basis of the deduction is simply that it is found to be correct when it is possible to check it by comparison with fossil remains.

With this principle in mind, even a casual visit to a zoological gardens is suggestive. An examination of human and ape skeletons such as an anatomist can make is even more so. The layman's amateur impression of

grasping hands, man-like curiosity and half-understanding face, can be reinforced by a concrete series of resemblances in structure. To this the veterinary surgeon can add that anthropoid apes are almost as susceptible to typhoid as are human beings; and that the chimpanzee, alone of the animal world, is liable to develop appendicitis when kept in captivity. No less impressive are the results of blood tests carried out by biochemists. Not merely has the blood serum of old-world monkeys been proved to be closely related to that of man. The relationship is closer than to that of their fellow monkeys of the new world. Finally, there are a number of vestigial traces which serve as further pointers to man's ape-like past. There is, for example, a muscle in the neck of a monkey which helps to lift the shoulder. That muscle is found in the great apes, although considerably reduced in the gorilla and chimpanzee, but only very rarely in man. Here, it seems, is an obvious example of the gradual degeneration of an adjunct which has long since ceased to be necessary.

The second line of argument is based on the embryo development of the human baby. It appears that every organism passes, in broad outline, during its life-history through the same stages of development that the race to which it belongs has followed. Embryo development, in fact, provides a rough, enormously speeded-up picture of the course of evolution. The young of all related species are, for example, always very much more alike than are the same individuals when fully grown—a pointer to a common ancestry. It is also known from the evidence of fossils that fishes were the first vertebrates to make

their appearance; and the embryo of every mammal passes through a "fish stage", to the extent at least that it is equipped with embryo gill slits, as if it expected to live an under-water existence.

To this general rule the human baby is no exception. Like all mammals it passes through a fish stage. Resemblances to other mammals naturally survive to a later stage of development. The tail of an embryo baby is, for example, at one time longer than its legs, and even at birth it is nothing very uncommon for a baby to have a small tail. A few rare instances are even known of adults with tails. If we want a general relationship to the monkey family we can turn to the tuft of hair which all lemurs carry on their wrists as an aid to their sense of touch. Lemurs are not, of course, monkeys. They are, so to speak, half monkeys, now mainly confined to Madagascar and South Africa, one of nature's unsuccessful attempts to reach full-blown monkeydom. That tuft of hair is not found in any true monkey. But it is found in embryo monkeys, as well as in embryo human babies—again an indication that monkeys and men have a common ancestry, and that their common ancestry is in the lemur direction.

Finally, following the same principle further, it is worth noticing that the proportions of a young baby are more like those of an ape than of a man. He has short legs, relative to his arms and body, and his legs are curved as are those of an ape. Altogether there are a good many indications of the general direction in which man's ancestry lies. They do not, it is true, amount to

proof. But they do represent a high degree of probability—a probability which is enormously strengthened by comparison with the known facts of animal evolution. No biologist, at any rate, has the slightest doubt as to their general interpretation.

The theory of evolution having been formulated and the general lines of animal evolution worked out, it was inevitable that a search should be instituted for "missing links" which should definitely establish the connection between man and his supposed ape-like ancestors. To some slight extent the necessary evidence was already available in Darwin's day. But only one of the now recognised races of early man had as yet been discovered, and its significance was only dimly appreciated. Broadly speaking, however, the belief was held that man and the great apes had diverged at different periods from a single common stock; and that man's steady upwards progress would be speedily revealed in a succession of fossil skeletons, representing all stages between "low-brow" apedom and "high-brow" humanity. The result can best be examined by looking in succession at a few of the more important discoveries which have been made. They have all a direct bearing on the problem of man's ancestry as we can see it to-day. Only so can we see how far hopes have been fulfilled, and how far disappointed, and along what lines the trail of future discovery may be expected to lead.

The first scene is set in Germany in the Neanderthal cave, high up a limestone cliff in the valley of the Düssel. The time is 1857, two years before the publication of *The*

Origin of Species. Yet an Elberfeld physician, Dr Führbrott, is already interested in the early animal and human remains which he believes the cave may contain. He eagerly awaits its clearing by quarrymen, paying frequent visits to the neighbourhood so that he shall miss nothing of importance. He is rewarded by the find of a human skull and limb bones. This is the original Neanderthal man, whose relations have since been recovered from France, Belgium and Moravia, as well as Palestine. The latter extension of the range of Neanderthal man is, however, quite a recent discovery. In a cave on Mount Carmel Miss Dorothy Garrod and Dr Theodore McCown have discovered a whole series of skeletons, of all stages of development, which though apparently a distinct racial type are certainly closely related to Neanderthal man. His teeth, which in the light of known complete specimens are alone sufficient to establish his identity, have also been found as far apart as Malta and the Channel Islands. He must therefore have ranged over the greater part of Europe, as well as along the eastern and probably the African shores of the Mediterranean. If he could not himself be described as a missing link, he at least suggested that one would sooner or later be found. He had a full-sized human brain, was capable of fashioning for himself stone implements of excellent workmanship, and he buried or provided protection for his dead. On the other hand he had pronounced eyebrow ridges, like those of the gorilla and chimpanzee, his skull was low and ape-like, and he must have had a slouching, ungainly walk. He lived about 50,000 to 20,000 years ago and, on the sup-

position that he was a direct ancestor of modern man, his discovery suggested that human evolution had proceeded at quite a rapid pace.

Each of the remaining discoveries which need be mentioned belong to a very much earlier period—perhaps half a million years ago, although it must be admitted that dates at this stage of the earth's history have very little meaning. When geologists talk in terms of tens or hundreds of millions of years, the figures which they quote are more or less precise. They can be based on the radium scale, already mentioned. For more recent periods geologists are dependent on the succession of warm and cold, and wet and dry periods, which the record of the rocks discloses. Ice ages are directly shown by the traces of old glaciers, and changes in climate generally are clearly reflected in corresponding changes in plant and animal life. There is no doubt about the sequence of events in any one country or continent. The difficulty is rather in the correlation of climatic changes in different parts of the world.

It is as if some future generation of historians were deprived of all dates relating to recent history, and were compelled to refer events in England to the reigning monarch and in America to the name of the then president. The order of events in each country would be known with certainty, but exact estimates of time would present difficulties, and so would any comparison between dates in one country and dates in another. On the other hand they might be able to see a connection between America's Recovery Administration and the formation of a National

Government in England, and so would not be wholly in the dark.

In view of these difficulties, Dr A. Tindell Hopwood of the British Museum has made the interesting suggestion that anthropologists should adopt what for want of a better term may be described as the "elephant standard". He believes that the difficulties involved in comparing ice ages in different parts of the world should for the moment be put on one side, and attention concentrated instead on the stage of development reached in the animal world. For this purpose he has made chief use of the elephant, with the horse and ox as useful subsidiary guides. If this idea is accepted, some readjustment will be necessary in the relationships between the various races of early man to be described—but not, however, in their general antiquity. With this warning, we may now proceed to the next scenes in the pageant of discovery. Orthodox opinion is that these various episodes in man's history must be regarded as roughly contemporary. If we want to give them a date, then half a million years ago is probably as plausible as any, but we should be prepared to recognise that the figure quoted might perhaps be anything from a quarter of a million to a million years according to taste.

From 1857 we may pass to 1891 when Dr Eugène Dubois, a surgeon of the Dutch colonial medical service, discovered the much-discussed remains of the Java "ape-man" in the island. Here, it seemed, was a genuine missing link, and of enormously greater antiquity than anything which had been found before. Java man was

at first claimed to represent a half-way stage between ape and man. Nowadays, however, he is generally regarded as more nearly, if not quite, human. It is really a question of where the dividing line should be drawn. From the pattern which his brain left on the inside of his skull, anatomists have been able to discover that he already possessed all the principal areas characteristic of the human brain. They were much less well-developed, but none the less clearly recognisable. He must have been much slower at learning than we are, and it is doubtful if he can have been able to talk, at any rate in the accepted sense of the word. Estimates of the size of his brain give a similar picture. An average brain size for a gorilla is about 600 c.c. That of Java man was probably about 900 c.c., which in any existing human race would imply that its owner was an idiot, a fair human average being 1350 c.c. The gap between Java man and the lowest of modern races is, however, appreciably less, and he both walked upright and had teeth sockets of human form. Call him ape-man or man, he had travelled more than half of the upwards path towards humanity.

The next important discovery, made in Germany in 1907, gave the first indication of the complexity of the trail. It was the finding of a solitary jaw-bone in a sandpit at Mauer near Heidelburg, 78 feet below the present ground-level. Although from the conditions under which it was found, it appeared that its owner must have lived only a little later than Java man, the jaw itself proved practically indistinguishable from those of the much later Neanderthal men, who it will be remembered

were unquestionably human and had full-sized modern brains. The brain of Heidelburg man, Sir Arthur Keith believes, must also have been large, and he is most naturally regarded as an early prototype of "low-brow" but intelligent Neanderthal man. In evolution, as well as geographically, Heidelburg is a far cry from Java.

So far we have visited Germany and the East Indies. The next scene is set in Sussex. The year is 1908, and a lawyer, who is also a naturalist, is taking a country walk near Piltdown, a few miles north of Lewes. He is walking along a farm road, and his eye is caught by the fact that its surface has been repaired with flints of an unusual colour. Out of curiosity he makes enquiries and discovers that the flints have been taken from the farm gravel pit. Like the German doctor who discovered Neanderthal man, Mr Charles Dawson was hopeful that the pit would prove to contain early remains. Three years later his hope was fulfilled, and Mr Dawson's name is commemorated as the discoverer of the first human skull comparable in age with that of the Java ape-man. Near the skull of Piltdown man were also found the remains of the prehistoric mastodon, hippopotamus, beaver and elephant—strange inhabitants for a Sussex farm.

Like the Java ape-man, Piltdown man was not remarkable for the extent of his recoverable remains. In addition to the greater part of his skull, there were found his right and left thigh bones, a shoulder-blade and upper arm bone and his pelvis. Although the first reconstruction of his complete skull by Sir Arthur Smith Woodward, then at the British Museum, differs from that afterwards made by

Sir Arthur Keith, there was at no stage any dispute that Piltdown man was genuinely a man. In brain size he falls well within the range of modern man and, according to the latter, his skull must have been very little different from that of modern man. The same conclusion is supported by examination of the various bones found: the only ape-like characteristics of any significance were those of his jaw and teeth. Here, therefore, was a man, probably not very different from man as we now know him, living at the same time as the Java "missing link". As, however, the age of the gravel terrace in which Piltdown man was discovered was at first underestimated, it was not at once realised that the ape-man's claim to be regarded as a genuine ancestor was already threatened.

The demolition of this claim was completed by the discovery in 1927 of Pekin man, probably the best known representative of any of the early races of man and, like Neanderthal man, unquestionably a cave dweller. The manner of his discovery and recognition provides an extraordinary example of international co-operation. No less than seven countries can claim a share of the credit. The man who first became interested in the limestone caves of Chou Kou Tien was a Swedish geologist, Dr J. G. Andersson, who seven years earlier had happened to visit the district on business. He found that the hard rock, formed by the lime-laden drip from the roof, contained the bones of a large number of prehistoric animals. The work of removal was difficult, a considerable amount of blasting being necessary. Dr Andersson was not, there-

fore, able to complete the exploration of the caves before business distractions intervened. He had already been able, however, to date the cave deposits with considerable accuracy from the prehistoric animals found. Once again they proved to be roughly contemporary with those of the Java ape-man. At this stage Dr Andersson handed over the work of excavation to a young German geologist, Dr Otto Zdansky.

It was the German, Dr Zdansky, who discovered the first human relics in the shape of two teeth—although, curiously enough, the actual discovery was made, not in China, but in Sweden, whither he had removed the complete fossil collection for examination. When the news reached Pekin, the Chinese directors of the national geological survey decided to rush forward the exploration of the cave deposits. The immediate result was the discovery of a third tooth, which was at once identified by a Canadian, Professor Davidson Black of the Union Medical College, Pekin, as representing a new family of mankind. On the strength of this one tooth, for he had not seen the two others, he invented a new family "Sinanthropus", which means "man of China", and a new race "Sinanthropus pekinensis", otherwise Pekin man. This is a point of some interest, because the criticism is very commonly made by laymen that anthropologists are only too prone to base wide conclusions on apparently slender evidence. On this occasion the evidence might certainly seem slight. But the caves of Chou Kou Tien were to yield, not merely three teeth, but two particularly well-preserved skull caps and a large number of bone

fragments as well. It was not long before the correctness of Professor Davidson Black's decision was fully confirmed.

England's connection with Pekin man is represented by the fact that Professor Black owed both his training and inspiration to Sir Grafton Elliot-Smith, who was then working at Manchester. Indeed it was no chance that Professor Black was in China. He had accepted his Pekin appointment because he hoped that it would give opportunities for just such work. Finally we may complete the international inventory by recording that the necessary funds for excavation were supplied by the Rockefeller Foundation and that the archaeologist of the party was a Frenchman. Sweden, Germany, Canada, China, England, the United States and France—it is no bad record for a single scientific discovery.

Pekin man is remarkable not only for his age but, in comparison with Piltdown man, for the extent of the remains recovered. Indeed, from the stone tools and animal remains found nearby, we know a good deal also about his way of life. Although unquestionably human, however, he was also unquestionably "low-brow". In brain size he is nearer to the ape-man of Java than to the average modern man. At the same time he comes within the limits of size for living races. And, even if nothing were known of his habits, he would still be accepted, without the possibility of criticism, as a man. In many points, for example the form of his ear passages and in the way in which his jaw was attached to his head, he is almost "modern". On the other hand he showed a number of

ape-like characteristics and can best be described as a more progressive cousin of the Java ape-man.

One important lesson which anthropologists learnt from the discovery of Pekin man was the complexity of the problem which faced them. He was a contemporary, if at the other end of the world, of Piltdown man. Yet the two races differed considerably more from one another than a negro now does from a Chinaman. It was clear that the modern races of mankind could no longer be pictured as diverging uniformly, along with the great apes and the extinct Neanderthal race already mentioned, from some common ancestor. There was greater divergence half a million years ago than there is now; although, if anatomists have failed to find simplicity, they can at least console themselves with the reflection that Piltdown and, even more, Pekin man was very much nearer to apedom than is modern man.

So at this time, which we have agreed to call half a million years ago, we have recovered from Eastern Asia, first the original Java man, making no more than his first steps across the threshold of humanity; then Pekin man, larger brained but not so very different anatomically, already living a relatively comfortable existence at the expense of neighbouring game; and from Western Europe, almost exactly on the opposite side of the world, Heidelburg man, a little later than the others, interesting only as the forerunner of a long extinct race; and finally Piltdown man, in most ways surprisingly modern and alone, perhaps, of all these early races, a genuine ancestor of our own. Even from these few representatives

it is evident that man's genealogical tree has many branches.

The difficulty is rather in the paucity of the remains discovered than in the presumed complexity of man's advance. It took nature some fifty million years to decide that her experiment of giant reptiles was doomed to failure, and even the apparently straightforward progress of the horse was accompanied by a number of offshoots from the main evolutionary stem which, for one reason or another, failed to perpetuate themselves. Surely we may imagine that man was worth a similar expenditure of wasted effort? Whatever may have been thought when the quest for "missing links" was first undertaken, it would have been more a matter of surprise if the task had proved an easy one.

Two great continents have so far contributed little to our knowledge. In America no remains of very early man have been yet recovered, although geologists say that the Behring Straits must more than once have been merged in a land connection with Asia, so that migration between the two continents must at times have been possible. Even more important, perhaps, for the future is the evidence that surely lies hidden in Central Africa.

In the gravel beds of Oldoway gorge of Tanganyika, Dr L. S. B. Leakey has found the most complete sequence of early stone tools which has yet been recovered from any part of the world. Here, it seems, must have been an important cradle of early humanity and, if the Oldoway gorge does not go far enough back in time to rival Piltdown or Java, it at least seems probable that elsewhere in

Tanganyika or Kenya it should be possible to recover human remains of comparable date. At any rate the existence of the Oldoway tool sequence, coupled with the relative modernity of Piltdown man as compared with Pekin, has led many anthropologists to the view that the most direct clue to our ancestry is to be sought there. The stock of Europe-Asia has been rising—and Europe has been relatively well explored.

It is impossible therefore to avoid reference to the only precise claim which has been advanced on behalf of any early African man[1], even if high hopes have given way, at the time of writing, to disappointment. Little more than three years ago, it was claimed by Dr Leakey that he had discovered, by the Kavirondo Gulf of Lake Victoria Nyanza, the lower jaw of a hitherto unknown race of early man, barely distinguishable from one of modern type, yet roughly contemporary with the other early races already discussed. Even Piltdown man, it will be remembered, had shown ape-like characteristics in his jaw and teeth. So important was the find considered that an international conference of experts was called at Cambridge, England, to consider their significance. It was agreed on the evidence submitted that Kanam man, as he was christened, was all that his discoverer claimed him to be. The time scale of human evolution had, it seemed, to be enormously extended. So little different was the man of Kanam from modern man, that the men of Piltdown and

[1] Unless we include the Taungs skull from South Africa, now generally regarded as representing an ape which was making the first steps towards humanity, the anthropoid equivalent of Java man.

Pekin appeared fated to join their more primitive contemporary of Java as two more of nature's unsuccessful efforts to reach modern humanity.

Then, in the spring of 1935, Professor P. G. H. Boswell, one of the most distinguished of English geologists, joined Dr Leakey on a further African expedition. In view of what followed it should perhaps be emphasised that Dr Leakey had himself pressed Professor Boswell to go out. His report, briefly summarised, was to the effect that no adequate steps had been taken to identify the site of the discovery, either on the ground or on a map; that it had not so far been possible to rediscover the site; and that the geological strata of the district were in any case liable to "slipping" and to that extent were unreliable for the dating of any remains found in them. His verdict was therefore that Kanam man must be placed in a "suspense account", and Mr E. J. Wayland, the Director of the Geological Survey of Uganda, was stated to have agreed. It is only fair to Dr Leakey to add that, at the time of writing, he is still in Africa and has not yet had an opportunity to offer any reply. In the mean time the position has been left very much where it was before. Kanam man may prove to be all that was hoped of him—or he may not. Africa may or may not be the continent in which the earliest remains of modern man will sooner or later be discovered. It is only unfortunate that a claim which had been so authoritatively accepted should have been so soon rejected, and that future discoveries in this part of the world may be liable to be treated with greater caution than the evidence would warrant.

With considerably less uncertainty, we can study our relationship with the living apes. A census of the structural features of the higher primates, made by Sir Arthur Keith, is of particular interest from this point of view. Of the features selected from man's body for comparison, 10·5 per cent. proved to be possessed in common with all three of the great anthropoids—the gorilla, chimpanzee and orang outang. A further 8·7 per cent. were shared with both the gorilla and chimpanzee, but not with the orang outang. Still another 9·2 per cent. of features were shared with the chimpanzee only, and 8·1 per cent. with the gorilla only. By selecting different physical features for comparison, other experts would no doubt arrive at different figures. But the general conclusion seems clear. The gorilla and the chimpanzee show the closest resemblances. We cannot exactly say that they are our nearest relations, for it is probable that the human stem split from the ape stem before the ape stem split into its three modern representatives. From the point of view of the constructor of pedigrees, all three are equally distant cousins. It is rather that the gorilla and chimpanzee have evolved most nearly along human lines.

Now let us go back a stage farther, and ask which of the existing anthropoids represents the nearest living approach to the common ancestor of man and the apes. Here, again, we can give a reasonably definite answer. But in order to do so, we must turn to the fourth family of anthropoids, the gibbons. This is the term used to describe the smaller anthropoids of the Indo-Malay countries. In skull and teeth the gibbon is the most primitive

of living apes, although it is also the most highly specialised as regards length of arm and general adaptation to tree life.

It is the gibbon which shows the closest resemblance to a very early ape, known as "propliopithecus", the remains of which were found in Egypt in 1910. This lived perhaps fifty million years ago, and is placed by Sir Arthur Keith near the main ancestral line of all modern apes. On anatomical grounds he considers that "propliopithecus" moved approximately in the same manner as the modern gibbon, and that in general characteristics the latter may be presumed to have undergone smaller changes than any of the great apes.

The modern gibbon shows a straightening of the lower limbs while climbing suspended from its hands. This quality has become a definite possession in the greater anthropoids, and may show the mechanism by which man attained his straight legs. The same hanging position is held responsible for the slight curve in the lumbar region of the spine which is noticeable in gibbons, and becomes increasingly accentuated in the greater anthropoids and in man. It seems therefore that the gibbon may be taken as a rough approximation to an earlier stage of our ancestry; just as a compromise between the gorilla and the chimpanzee is as near as we can get, among existing species, to the great ape stage of our development.

Finally we must add one last question mark. It is represented by the phrase "parallel evolution", a possibility which there is no need to discuss in any detail. It

means that nature may produce the same evolutionary result in different species quite independently; that, because man and the ape have a large number of physical characteristics in common, it does not follow that they have a common ancestor who possessed them all. This theory, and it is rather more than a theory in some cases, does not deny propinquity of relationship. Still less does it deny evolution. It merely means that it may be necessary to go very much farther back to find common ancestors between different species and groups of species than has been formerly supposed. So far as the ancestry of man is concerned, its chief exponent is Dr Fairfield Osborn of New York. In opposition to Sir Arthur Keith and Sir Grafton Elliot-Smith, he holds that man was never an ape. But Dr Osborn has never denied that man must have passed through an ape-like phase, or that the common ancestor of man and the apes must, according to this theory, have been something very much less dignified than even a modern ape. The difference is therefore only one of degree.

Dr Osborn has never denied human evolution, in spite of much misrepresentation to the contrary. At the same time the full acceptance of his views would undeniably make the task of the anthropologist very much harder. In order to obtain a complete picture of our ancestry, and of that of our cousins the apes, it would be necessary to follow out the history of each species separately through a fabulously long period of years. One day it may be possible to decide between Dr Osborn and his opponents. In the mean time anthropologists will be quite content if

they can push back man's own ancestry through another million or so years.

No one doubts that in the long run they will be able to do so. Anthropology differs from all other sciences in that it cannot arrange its own experiments. Dealing essentially with the past, it can only do the best it can with whatever relics of the past chance may elect to provide. The mere fact that the men of half a million years ago are not wholly lost to us, suggests that further specimens may in time be discovered; while, if man was as far advanced as we now know that he was at that date, there is no reason why discovery should stop there. Only a minute fragment of the earth's surface has been dug to any depth. Only a minute fragment of what has been dug has received expert scrutiny. No serious biologist doubts the reality of human evolution. It is merely that its trail is proving both longer and more complex than, in the first flush of enthusiasm, was originally supposed.

In the meantime we may be content that, as a result of less than thirty years' work, more than four hundred thousand years has been added to the span of human history. If man cannot add a cubit to his stature, his past at least seems capable of almost infinite extension. As for the future, Sir Arthur Eddington has estimated that our sun, in all its ten thousand million years' history, has not used up more than one-tenth of its original store of heat energy. Certainly it must have thousands of millions of years of active life before it, and not until the earth is many times older than it now is does there seem any possibility that life will become extinct. If, therefore,

some of us find our ape-like ancestry repugnant, we can at least take consolation by looking forward to a still further increase in human dignity. We ourselves may one day be classed as "Palaeoanthropidae", low-brow, incomplete.

CHAPTER VIII

THE BEGINNINGS OF CIVILISATION

FIRE and agriculture are the two most important discoveries in human history, but no one knows when or where they were made. Without agriculture there could have been no fixed settlement. Man, so long as he is a hunter, must follow the game on which he feeds. He requires also somewhere about a square mile of land to support himself, and much the same limitations apply in so far as his diet may be vegetarian. Whether through game or wild fruits and roots, he is dependent on the bounty of nature, and none of the developments which may follow from organised life are possible. The hunter will have no time to clothe himself in elaborate garments, nor will his home be ever sufficiently permanent to encourage any form of lasting endeavour. So long as he is solely occupied in keeping alive he will have no time for specialisation.

All human endeavour represents, from one point of view, man's struggle to be independent of his environment. If this is true in the case of agriculture, it is even more evident as regards the use of fire. Fire enables man to keep warm at least, even if to this day he has not wholly solved the problem of keeping cool. It also increases the range of palatable foodstuffs; and enormously increases the use which can be made of metals, as well as the ease

with which they can be secured. It is the basis of both effective pot-making and effective brick-making, and in modern industrialised life it plays an even bigger part. It not only provides us with light and heat, but with every form of power except water and wind power. There is virtually no commercial process which is independent of fire.

Yet when we begin to enquire into the origin of fire we are rapidly driven from the more or less solid ground of archaeological discovery to the speculations of anthropologists. Archaeologists can only point to the charcoal and "pot-boilers" found in association with the early races of man, and assure us that they had the use of fire. Pot-boilers are the stones used by early man to warm his pots. The stone was first heated in a fire and then dropped while still hot into the pot. Repeated heating and cooling caused it to develop characteristic cracks which, to the expert eye, are unmistakable. Sir Arthur Smith Woodward has lately found one such pot-boiler, together with charcoal, in the same geological layer from which the remains of Piltdown man came. Other pot-boilers have been found in association with Pekin man's remains. Therefore, however much is still uncertain, we can be sure that fire was in roughly simultaneous use in Western Europe and farthest Asia somewhere about a million years ago.

That the use of fire should have been known at so early a stage in man's history is itself an indication that its discovery was an accident. It is true that man's brain power has not, to all appearances, increased so very greatly in all

the hundreds of thousands of years of his history. But how many modern humans would be capable of lighting their own fire without the aid of match or tinder? The proportion would be much lower than is generally realised, although we know in advance that fire can be obtained by rubbing two sticks together. On the other hand, lightning and volcanic eruptions are both capable of starting fires without human intervention. So may a falling meteor, or the sparks thrown among dry material by a boulder on the move. It is so much easier to keep a fire alight than to light it that a natural blaze may well have provided both the inspiration and the opportunity for man's first use of fire.

No doubt one of his first discoveries was that fire might be a defence against animals. This would be naturally suggested by their obvious terror, shared also by himself, in the face of an advancing forest fire. A little later the discovery must have been made that it could also be employed to drive game in the direction of the hunters. Perhaps even before this it would have been noticed that the smoke from a camp fire could be used to indicate the whereabouts of those tending it, and so a system of smoke signalling was built up—man's first telegraphy. Judging from the customs of primitive peoples to-day, the use of fire for signalling must go back a very long way. As a matter of interest, although at a much later period, fire signalling is mentioned in one of the very few letters which provide direct and contemporary corroboration of the Old Testament narrative. This letter was one of a group, written on fragments of broken pots, which have

been lately found in the burnt ruins of the citadel of Lachish. Others of the letters show that they must have all been written in the last days of the city before its sacking by Nebuchadnezzar. This one contained a vigorous denial by the commander of an outpost of a suggestion that he had not been keeping an adequate look-out for fire signals from the city.

Whatever may have been the order of these later inventions, there is at least good evidence that man's original discovery of fire was an accident. It is provided by the systematic study of primitive customs and beliefs. The sacred lamp which burns at the altar of modern churches is probably the direct descendant of earlier sacred flames, which must at all cost be tended in the interests of the community. Even to-day there are tribes which keep their fires alight from one year to another. The Andaman islanders, for example, are said to be ignorant of the art of producing fire. Yet they have the use of it and, whether or not their ignorance is as complete as has been suggested, they certainly take a smouldering stick with them when they go out on an expedition.

The same suggestion is reinforced by legends culled from many parts of the world. Anthropological evidence of this type is admittedly, from its nature, speculative. Yet it is one of the truisms of anthropological enquiry that every legend must have an origin of some kind, and one of the chief objects of anthropological research is to separate the odd few grains of truth which a legend may embody from its overlying embroidery. In this case there is a considerable body of evidence that

the accidental friction of one stone upon another was the origin of human fire; and a considerably larger body of evidence that the discovery of fire was an accident. From the Shahnama of Persia comes the story that the ancient hero Hushenk aimed a boulder at a snake, missed his target, and showed man fire. A similar, but less plausible, legend is attributed to the aborigines of Australia, and in the legends of American tribes both the buffalo and panther have been credited with first striking fire from their feet. Similarly the sign of the Mexican god, Quetzalcoatl, was a flint. In all these stories there is an element of coincidence. No single one, by itself, would carry much weight. But taken together they constitute evidence which cannot, at the lowest, be wholly ignored. It is moreover evidence of quite a different kind from anything else which we shall meet in this volume.

Fire, however, is but one step, although an important one, along the path to civilisation. Its discovery must have increased man's comfort, extended the range of climate in which he could live and given him a certain amount of new power over beasts. More important in the long run, it enormously increased his scope for showing further ingenuity. But the fact remains that until the discovery of agriculture, man's activities must have been lamentably limited. At this point climate and physical conditions must have played a vitally important part—how important we can best guess by looking for a moment at the various types of existence which primitive man can follow.

One of the first lessons to be drawn from the habits of modern peoples is that life in any form of open country is inimical to progress. We have only to look at the aborigines of Central Australia to see how very nearly impossible it is for human beings to maintain their existence under such conditions. Man's upright stance is then, in many ways, a handicap. In proportion to his size and strength he can be seen a long way off by the animals he would hunt. There is little or no cover, and the animals themselves are to all appearances in league against him. Those which he could most easily kill are all highly specialised for speed, for the obvious reason that speed represents their only chance of escape from their natural enemies. Even if man has learnt to tame the young of various wild animals, again probably a chance discovery, his further progress is still very limited. To obtain the necessary grass food for his flocks, he is compelled to keep on the move. At the same time personal possessions must be kept down to a minimum. This is the sort of existence to which we are introduced in the book of Genesis. Flocks and herds are the sole measure of wealth, and the children needed to look after them "an heritage and a gift". Under such conditions life may become both very stable and very specialised. The wandering Arab of to-day leads a life not so very different from that of Abraham; and it is certainly no chance that the people of Israel only began to develop in a material sense after they had learnt the ways of Egypt and settled in "a land flowing with milk and honey". Something, either the pressure

of climate or an invading people, is needed to stir the nomad to progress.

A purely hunting life is very much more promising—provided that there is sufficient game for a settled existence to be possible. This is a condition that is most likely to be satisfied in forest country. Then the women and children can be left at home while the men hunt. With the beginning of a settlement, however humble, comes the opportunity for experiment and the urge to improvement. The women, it is true, will have much else to do. But there are many ways in which chance discoveries might be made. Fruit or nuts, not too skilfully stored, may begin sprouting of their own accord. Seed thrown to the ground may show green life. In either case a child's casual care, frowned or smiled on, may be sufficient to turn the balance. Within a few months a chance discovery may be transformed into a promising invention. More of the world's great inventions have been due to chance than is generally realised. It was so with the invention of splinterless glass, stainless steel and artificial silk. For primitive man, lacking all approach to scientific knowledge, the role of chance must have been even more important.

The fact that it has already been invoked in the case of fire is no reason why it should not also be invoked in the case of agriculture. Incidentally, whereas fire was in all probability a male discovery, made while out hunting, there is at least some reason to suppose that agriculture was the invention of either women or children and made at home. If only to restore man's self-respect, it may be

of interest to notice that yet a third important invention, that of writing, can be claimed by the male sex. Recent excavations suggest that the earliest pictorial signs originated in either magic or the necessities of business communication. So it seems that Rudyard Kipling was technically in error when, in one of his most delightful *Just So Stories*, he credited the child Taffy with the invention of writing. But if he was technically wrong, he has the most eminent support for his idea that, in a sufficiently primitive existence, the male will be too busy to be inventive.

So far we have arrived, admittedly on rather sketchy grounds, at the conclusion that the possibilities of agriculture were first discovered in a country which was sufficiently well watered to make a settled hunting life feasible. As we shall see later, the science of plant genetics enables us to speculate also as to the part of the world in which this first happened. In the meantime we may notice that rather different climatic conditions are required for the next stage in human development.

In the beginning, we may imagine, man would cultivate his little plots beside his dwelling until the fertility of the ground was exhausted. He would wonder what had gone wrong with his great invention, and in time he would discover that by again using virgin soil its utility could be restored. So long as the plots were small, and one or two families were living by themselves, there would be no great difficulty. But, in any larger society, the whole village or tribe would be compelled to move in search of new land. And, in point of fact, anthro-

pologists find that this still happens to a certain extent to-day. So the virtues of settled life are in part destroyed. A limit is set both to the number of possessions which can be conveniently transported, and to the complexity of social organisation which is possible. There is no sense of permanency.

Only for peoples living in an alluvial valley is this difficulty removed. There the soil's vitality is renewed, without the need for human intervention, by the annual invasion of flood water. Later, as in Egypt, an artificial irrigation system may be introduced to enable a wider area to be cultivated. But this also would be naturally suggested by the periodic occurrence of floods, just as the equally important problem of manuring had been naturally solved. We should therefore expect to find the first large-scale cultivation of grain in alluvial valleys and the first beginnings of agriculture at not too great a distance from them. Archaeology can tell us of the early practice of agriculture, so far as the implements used and the grain itself have survived. The science of plant heredity can explore, mainly on theoretical grounds, the probable origin of cultivated barleys and wheats, and so tell us in what part of the world they may be supposed to have had their origin. The spade illumines one aspect of the problem; the collecting botanist and the laboratory expert the other. It is one of the most curious and, at first sight, one of the most unexpected, alliances in the whole history of scientific enquiry.

It may perhaps make for clarity if we begin by looking at the neatly dovetailed solution which, only a few years

ago, these two sciences could plausibly put forward. Not that the structure has in any real sense collapsed. It is rather that a number of new pieces have been discovered, which have somehow got to be fitted in; and that, in the process of fitting, much that was there already has had to be taken down and replaced—differently.

The problem, then, was to decide which of the two known early centres of civilisation, Egypt or Mesopotamia, had developed first. There was no doubt that these two centres were early in contact. It was natural, therefore, to suppose that one or other country had first achieved the essential advance from barbarism to organised life, and that thereafter they had proceeded on the basis of mutual influence and exchange of ideas. Details would naturally vary as between the two countries, but the main technique of existence seems to have been broadly similar. The great intriguing question was, which came first, Egypt or Mesopotamia?

Egypt, on historical grounds, could at least claim the first fixed date. It arose from the fact that the Nile flood, then as now so vital to the Egyptian farmer, happens to coincide with the heliacal rising of the star Sirius, which the Egyptians called Sothis. So it was that when they invented the calendar, no doubt as a guide to their agricultural operations, they took the rising of Sothis as the beginning of their year—just as we, if a single day had happened to mark the beginning of Spring, would no doubt have taken that day as ours. But, as was only natural, they did not realise that with a year of exactly 365 days and no leap years, they were steadily getting

ahead of the natural year. Gaining a matter of six hours a year, it was only every 1460 years that the rising of Sothis coincided exactly with the beginning of the official Egyptian year. This slow procession of the seasons must, one would have thought, have been disconcerting. But for the archaeologist it has definite advantages. We happen to know that in A.D. 139 the Egyptian calendar and the sun's calendar were in exact agreement. There are therefore only a limited number of dates, separated from A.D. 139 by intervals of 1460 years, in which the calendar could have been instituted. 2781 B.C., which is one possible date, can probably be ruled out on the ground that the pyramids had been already built and that the calendar was in existence when the pyramids were built. So we are driven back to 4241 B.C.

This would in itself be evidence that agriculture was practised in Egypt some eight hundred years before the first of Egypt's many dynasties, for in addition to the obvious connection between the calendar and the Nile flood, the different official seasons bear such names as "Sowing", "Harvest" and so on. But, even by 1928, it could be asserted with certainty that the Egyptians had been for a long time farmers before they discovered the necessity for a calendar. It is generally agreed that the first dynasty should be dated to about 3400 B.C., and beyond that is a long period represented by numerous graves which have only been reduced to order by Sir Flinders Petrie's brilliant system of "sequence" dating. The forms of pots and their decoration, and even changing fashions in hair combs, were all pressed into service, until

the centuries could all be ranged in order. In this way, and allowing a reasonable death-rate in proportion to the graves found, Egyptian history was carried back between 1900 and 1928 from about 3400 to about 5000 B.C. The early predynastic Egyptian was already capable of making recognisable clay models of his cattle, while their successors of the middle predynastic period could undertake quite elaborate wall paintings and apparently delighted in a game resembling draughts. It was also known that barley at least was cultivated, although it was not certain to how early a date cultivation could be attributed.

The inevitably inconclusive discussion would no doubt have been still going on if two rather surprising discoveries had not been made. One was that a still earlier civilisation existed than any of the predynastic periods already mentioned; and the other that this pre-predynastic people, known as the Badarians from the place where their remains were found, had already discovered the art of agriculture. This was proved beyond all possibility of doubt when, in 1928, Mr Guy Brunton found a jar of a primitive type of wheat in an undisturbed Badarian grave. If these people, whoever they were, could cultivate wheat, so also could their successors—and if wheat, why not barley also? So the greatest invention making for civilised life was pushed back in Egypt to at least some hundreds of years before 5000 B.C.

Similarly, but not so completely, the curtain had been lifted from the early progress of Mesopotamia. Long before any of the names which are historically familiar—the Babylonians, the Medes and the Persians—we have

evidence of civilised life in the land of the two rivers. But the dating is even less definite than in Egypt, although it is certain that a king with the pleasing name of Mes-Anni-Padda reigned in Ur of the Chaldees somewhere about 3000 B.C. In any case, as we shall have to return to Mesopotamia later, it may be simpler to accept the conclusion of archaeologists that agriculture was probably practised in that country, as in Egypt, not so very far short of 5000 B.C.

This, then, is the archaeological part of the picture as it might have been painted a few years ago. There was no sound reason to give priority to either one country or the other. On the other hand, there is a considerable amount of evidence which suggests they were in mutual communication. Mesopotamian mace-heads, cylinder seals and so on have been found in Egyptian remains of 3100 B.C., and it is certain that the Badarian inhabitants of Egypt had trading relationships two thousand years earlier with a number of intermediate countries. The green malachite with which they painted their eyes may have been supposed to have come from Sinai, while the use of cedar and juniper wood suggests that they were also in touch with Northern Syria. It was therefore natural to suggest that these two civilisations had a common origin, and that the vital discovery of agriculture was made somewhere in between.

This admittedly rather nebulous suggestion could be supported, and at the same time made more definite, by the researches of botanists. Their part was to explore, so far as possible, the probable ancestry of modern wheats

and barleys, and to decide in what parts of the world they first appeared. Although the heredity of wheat is complicated, the general idea may be simply stated. It is that the evolution of the modern bread wheats has taken place in three stages, corresponding with the three groups of wheat which are found to-day. Each stage is supposed to have been evolved from the one before by hybridisation, all modern bread wheats falling within the group which from the point of view of heredity is the most complex. It is known, however, that wheats of the second stage, known as "emmer" were cultivated from very early times. One procedure was therefore to look for places where emmer grew wild, and to suppose that there it originated, and there also was first cultivated. This is not, for obvious reasons, a watertight argument, but it happens to be the line on which the problem was first tackled.

Ruling out various doubtful cases, the convenient conclusion could be reached that emmer only grows wild on the slopes of Mount Hermon in Syria, as nearly half-way between Egypt and Mesopotamia as makes no matter. Here, then, was the completed picture in which the contributions of archaeologists and botanists were harmoniously blended. On the slopes of Mount Hermon, or thereabouts, nature first provided grain suitable for cultivation. There also, some woman, wandering on the mountainside, chanced to collect some grains of wild barley and emmer, and to scatter them on open soil. The seeds sprouted and flourished, growing more closely than the natural grain, and the great discovery of agriculture

had been made. So, as others followed her example, the practice of agriculture became general among her people, and in time spread, at about the same period, to both Egypt and Mesopotamia. It is a pretty enough picture, and if archaeologists had only been content to leave well alone, there would have been considerably less excuse for including the origin of civilisation as one of the unsolved problems of science. As so often, new discoveries have brought new complications, and it is still by no means certain how the extra pieces which have been found are to be fitted together to form our new picture. It is only possible to enumerate the pieces and to point to one way in which it looks as if a "fit" may be secured.

It must, in the first place, be admitted that the conclusions of botanists have already been over-simplified in the effort to secure the desired agreement with archaeology. It is quite true that wild emmer may be to-day restricted to the Mount Hermon district, but it by no means follows that this was always the case. An entirely different method of looking at the problem had indeed been put forward by the Russian scientist, Professor Vavilov. His suggestion, which he has backed up by a great deal of detailed enquiry, is that where the largest number of cultivated varieties of a plant are found to-day, there that plant most probably had its origin. It is not, in the nature of things, a theory which is capable of either proof or disproof. It is, however, regarded as at least plausible by the majority of agricultural authorities, and leads to a very different picture. According to Professor Vavilov's theory the origin of both barley and Stage 2

wheat is to be placed in Abyssinia, on the far side of Egypt from Mesopotamia; and the origin of Stage 3 wheat in Afghanistan, on the far side of Mesopotamia from Egypt. Neither in the case of wheat or barley does he believe in the claim of Mount Hermon to be regarded as a place of origin. Gone, therefore, is the theory of the single beginning of agriculture, and of its simultaneous spread to Egypt and Mesopotamia.

Egypt, Mesopotamia and India have all made their contributions to the new picture—but the most direct contradiction to the old has come from Egypt. Sir Flinders Petrie, it will be remembered, had pierced behind the first of the dynasties of Egypt to a series of predynastic cultures. Behind them again, Mr Brunton had found the Badarians and had shown that even this pre-predynastic people had not merely had the use of agriculture and copper, but were in more or less regular contact with the outside world. Then, in the same season's excavations which proved that the Badarians were agricultural, Mr Brunton discovered a still earlier culture which he christened "Tasian" after Deir Tasa, the Nile Valley site where he first found its remains.

The most significant fact about the Tasians is that they seem to have lived in almost complete isolation from their neighbours. It is not merely that indications of trade are few. That is negative evidence and, to that extent, unreliable. There is the otherwise unexplainable fact that, within the space of two hundred miles, there seem to have lived at this time in Egypt three different and entirely separate peoples, each living their

own lives in their own way, and on the whole remarkably little influenced the one by the other. To the Tasians of Deir Tasa, Austrian excavators have added the Merimdians of Merimde in the Delta, while between, in the Fayum, Miss G. Caton-Thompson has found the third of these early peoples.

In spite of various differences, the achievements of Miss Caton-Thompson's people may be quoted in illustration of the general standard reached. They certainly grew flax, emmer wheat and barley, and kept pigs, cattle and sheep or goats. Harpoons were used to kill the fish of the lake round which they lived, and they were not above eating the flesh of the hippopotami which, no doubt, roamed in the surrounding marshes. For clothes they had linen woven from their own flax, but they also probably made use of skins. Pottery was evidently far from being a new invention, and their basketwork had reached a really high standard. Their chief weapon was a stone-tipped arrow, for they had not yet learnt the use of metals. But axe heads, arrow tips and sickles were skilfully sharpened. Only in their ornaments is there any suggestion of trade relations with other peoples. Perforated shells were brought both from the Mediterranean and the Red Sea to grace their womenfolk.

Here, then, were these three peoples, of broadly similar attainments, already master of many of the arts necessary for the development of civilisation, yet so far independent of one another that it is difficult to believe that they can have been at all closely linked with any of their more distant neighbours. Professor Vavilov believes that Abys-

sinia should be regarded as one of the original centres of agriculture. Is it not possible that the agriculture, and therefore the civilisation, of Egypt originated in the south and had nothing in its beginnings to do with that of Asia?

The story of Mesopotamia has undergone equally drastic revision. Until a few years ago it might be plausibly believed that archaeologists had only to dig deep enough to be able to fill in the missing chapters. Mesopotamia was regarded along with Egypt as one of the great centres of early civilisation. Surely, therefore, it must hold the clue to its own beginnings? So indeed it seemed. But archaeologists have now dug deep enough and they have come, not to the beginnings of Mesopotamian civilisation, but to estuarine mud. We can only conclude that at that far distant time when the land of the two rivers was first rising from marsh and mudbank, some already civilised people came in and took possession. That is the story as told by the pits dug by the joint Anglo-American expeditions to Kish and Ur of the Chaldees, as well as by German excavations at the Erech of the Bible story.

Paradoxical though it may seem, neither the houses nor the boats of the earliest inhabitants of Mesopotamia can have been so very different from those which are found to-day along the Tigris and Euphrates. They knew how to weave cloth and plait mats, and made fishing nets which they had learnt to weight with dried clay. They grew both corn and dates and, like the earliest Egyptians, knew the value of sheep, cattle and pigs. Certainly they were masters of the potter's art. Both painting and

indented patterns were used on the earliest Mesopotamian table ware, which was often exceedingly effective even by modern standards. Their spouted pots would be highly esteemed by the most fastidious hostess of to-day and, quite apart from their artistic merits, were of exceedingly delicate workmanship. There is here no question of admiring the primitive just because it is primitive. It is just that the early Mesopotamian potter had been bred in a sound tradition and knew his job. Moreover, there can be no doubt that trading was quite extensive. Bitumen, used in the plastering of clay mats, probably came from the wells near Hit on the Tigris. Copper cannot have been locally obtained, and two beads from the oldest houses at Ur suggest trade with either India or Armenia, although the identification of the stone in such cases must always remain a little doubtful. Obviously these people had a civilisation, and that of a high order. Equally obviously, they did not spring from the pre-existing mud. Where did they come from?

It would be too much to say that India, hitherto unduly neglected by archaeologists, has supplied the answer. But it has at least provided a clue. Quietly, and with the minimum of advertisement, the Archaeological Survey of India has carried back the history of the Indus valley until it must be as seriously considered as those of the Nile and the Euphrates in any discussion of the beginnings of civilisation. In the light of events, this is not perhaps surprising. Like both these other centres, the Indus valley is alluvial. Here, as much as there, conditions must have been favourable for the beginnings of

a settled life. Only somehow the possibility had been overlooked. Perhaps it was because expeditions, whether national or international, had to be sent out to either Egypt or Mesopotamia. Excavation in India was more prosaically undertaken by the men on the spot, and of these only Sir Aurel Stein attracted any great amount of international attention. Perhaps again it was a question of initial appeal. Egypt, after all, was the land of the pyramids, and Mesopotamia the land of Abraham. India was—neither.

India, in any case, has now come into its own. The excavation of Harappa and Mohenjodaro, both in the Indus valley but more than four hundred miles apart, has shown that Eastern India, as early as the third millenium B.C., was the centre of a great civilisation. Mohenjodaro covered at least a square mile, and both cities were carefully laid out. The larger houses had bathrooms, and the streets were drained. Sea fish were imported from the coast, jade from China or Burma, lapis lazuli probably from Persia, and shells from Southern India. There must have been trade in both directions with Mesopotamia and, judged by the relative absence of weapons, the Indus valley must have lived at peace both within itself and with its neighbours. Art, as illustrated by either pottery or statuettes, was at the same time complex, highly stylised—and definitely Indian. Both these cities were, moreover, rebuilt a number of times, so that the Indus valley civilisation must have been not only stable but long-lived. Indeed the very absence of change is one of the chief factors which makes dating difficult. To dig

deeper and deeper and merely find the same sort of remains turning up is merely tantalising to an archaeologist. Yet that is what has happened at Harappa and Mohenjodaro. It would have been quite impossible, from the evidence of these two cities, to have obtained any definite idea of their origin.

At a site near Amri, however, farther down the valley a definite clue has been found. Here, deep digging has resulted in the discovery of pottery of a different type—pottery that closely resembles some of the earliest Mesopotamian work. Both, for example, are painted, and the same colours are used in each, black for painting decorative bands and a characteristic plum red for filling in the gaps. Designs also are either similar or identical, particularly one which is generally taken to represent a row of birds in flight, although the figures are so highly conventionalised that it takes a good deal of imagination to recognise the birds. Strictly speaking, the comparison is with two different early Mesopotamian periods. The bird or "sigma" pattern belongs to the earliest or al'Ubaid period, so called after a site near Ur. The other resemblances, including the use of plum red as well as black, are with a somewhat later period called after Jemdet Nasr near Kish. Equally, there are sufficient resemblances to suggest that the people of Amri lie on the direct line of ascent of the later Indus valley civilisation. Inevitably the evidence is limited. Chronology, particularly, is very hazy. But it does begin to look as if these two great civilisations had, in part at least, a common origin.

To a large extent the riddle of their common origin is

the riddle of the painted pottery which archaeologists dig up with their remains. Mesopotamia and the Indus valley are some fifteen hundred miles apart. Yet along practically the whole route between these centres the chain of connection can be followed. Pottery resembling that of the very earliest Mesopotamian period has been found in Elam, on the Indian side of what was then the head of the Persian Gulf; again on the north shore of the gulf near Bushire; and inland at Persepolis in Persia and near the border of Persia and Afghanistan. The same "flying bird" decoration has been found by Sir Aurel Stein in Baluchistan between Afghanistan and the Indus valley. May it not be that somewhere in the intervening plateau, which stretches across both Persia and Afghanistan, this characteristic technique of pot-making originated? Professor Vavilov presses the claim of Afghanistan to be regarded as one of the original centres of agriculture. Is it not, then, natural to believe that Professor Vavilov is right; that it was in Afghanistan that Asia made the great discovery of how to grow corn; that it was in Afghanistan also, or the neighbouring plateau, that its first civilised arts had their beginning; and that the full flowering of this Asiatic civilisation was delayed until the all-important art of agriculture had spread to the fertile valleys of Mesopotamia and the Indus?

It is an attractive picture, attractive both in its simplicity and in the union which it implies between two quite different lines of enquiry. Professor Vavilov goes out with collecting boxes to secure as many different varieties as possible of wheat and barley. Archaeologists

take their picks and spades and, literally, dig up the past. It would certainly be gratifying if, from their quite different angles, they reached similar conclusions. But it must be confessed that a great deal more excavation will be necessary before the archaeological verdict is in any way final. There may be earlier sites in Mesopotamia still waiting attention. In the greater part of the intervening country, between Mesopotamia and the Indus valley, only a few isolated excavations have been undertaken. The necessary material is there, waiting to be unearthed. Its presence is attested by countless small mounds, any one of which archaeologists would be only too glad to explore were the opportunity theirs. It will certainly be a long time before the story of this mysterious hinterland has been fully pieced together. But it is certain also that this is a part of the world to which archaeologists will have to pay increasing attention, no matter what the practical difficulties. At present too many episodes are missing for it to be known if the sequence has been read aright.

Even now, it looks as if Persia and Afghanistan will not be able to tell the whole story. The Indus civilisation may have drawn its inspiration, as suggested, from their lofty plateau. Mesopotamia, already linked with the Indus, may also have been in their debt. But archaeologists believe that Mesopotamia was also influenced from another direction altogether—from Northern Syria where remains have been found which may well be earlier than anything in Mesopotamia. Here is a second trail, also leading backwards from Mesopotamia, but in almost the

opposite direction. It has been suggested that if this trail is pursued far enough back it will take us to another mountain country, Asia Minor. Here also there are many missing pieces. Here also there has been all too little excavation. But, such as it is, a speculative picture may be ventured. If we place yet another first centre of civilisation in Asia Minor, it must have spread on the west to Troy, a city which was old even when Homer sung. It must also have spread south to Syria, and thence influenced on the one hand Mesopotamia and on the other the bull worshippers of Crete.

So, little by little, man's early story is being rewritten. It has not, it must be admitted, been made any simpler in the process. But the archaeologist, like any other scientist, can only seek to explain the facts as he finds them—and the facts are by no means simple. Gone, now, is the possibility of linking the civilisations of Egypt and Mesopotamia and providing a common origin near Mount Hermon in between. Instead we are now provided with two, possibly three, "first centres". Egypt is left to itself, drawing its agriculture from the south, possibly Abyssinia. The Indus valley, an entirely new addition to the picture, may be similarly linked with Persia-Afghanistan. Mesopotamia is linked, on the east with this second centre, on the west with Asia Minor.

Instead of finding a single beginning, archaeologists have found a number of trails leading in different directions. About the significance of some of the clues there may be, indeed are, differences of opinion. But on the archaeological evidence available, the general conclusion

seems inescapable. Civilisation seems to have had more than one origin. Egypt, in particular, seems to have developed in its earliest stages independently of Asia. And yet, however suggestive the evidence, archaeologists are not satisfied.

Are we not, they say, asking rather much in the way of coincidence? Is it really likely that so many different discoveries should have been independently made? There is first the discovery that seeds can be sown and crops reared. Then someone realised that, instead of rubbing the ears of the corn as it stands, it is quicker and more satisfactory to reap with stone sickles. Someone else discovers that fibres, whether from cotton or flax, can be woven and made into clothes. Another genius, no doubt aided by accident, notices that certain clays can be baked to make beakers which will hold water. Then too there is man's habit of living in towns, or at least in settled communities of appreciable size. Even if we stop at that point, a considerable amount of ingenuity has already been exercised. How many of us, facing the question honestly, would regard ourselves as capable of making all or any of these discoveries? Is it likely that all of them were made two or three times, independently? That, at its broadest, is the real problem of the beginning of civilisation. Common sense, not always reliable, points in one direction. The facts, so far as they are known, in the other. Which is right?

CHAPTER IX

IS MAN A MACHINE?

NOWHERE is the scientist more deeply at a loss than in dealing with man himself. Atoms can be split, light from the most distant stars analysed, and electricity harnessed. But when the scientist turns to life, and even more to man, the difficulties at once become greater. Neither life nor man are so readily amenable to controlled experiment.

How far, it is natural to ask, can man's actions be explained in terms of the ordinary laws of physics and chemistry? Is he, putting the question in its old-fashioned form, a mere machine? To what extent is liability to disease, whether of body or mind, determined in advance, and to what extent could it be eliminated by sterilising the unfit? How far do the known laws of heredity, coupled with environment, determine human behaviour? Questions such as these involve, or border closely on, the nature of life itself. Translated into practical terms, they are of more than passing social importance. If man, for example, is in essence a machine, can he properly be regarded as responsible for his actions? Is punishment, other than as a deterrent, justified?

Leaving the main question on one side, is heredity something which is in the main fixed, or may the benefits of training and education be passed on, in part, from one

generation to the next? Again, how far are men the slaves of heredity as such, and how far of the conditions under which they are born and brought up? There is no doubt of the importance of the issues raised. In time, perhaps, complete answers may be provided. At present knowledge is "here a little, and there a little", which is no doubt the reason that biology has not yet been accorded the position of importance in public affairs which it must in time be given.

The biologists of a century ago were sharply divided into mechanists and vitalists and, so far as the rank and file were concerned, both were equally dogmatic. To-day no one is quite so certain. An increasing number of the mechanisms of life are being explained, but there is not the same assurance that life itself is no more than a mechanism. The procedure is one of elimination. This and this have been explained. Elsewhere it seems that ignorance may soon be turned to knowledge, but when all has been done there may still be something left to defy explanation and analysis.

The outsider who would guess the final issue can do little more than take note of a few of the outstanding cases in which the ordinary methods of scientific enquiry have been successful, and draw his own conclusions. Much of the knowledge that has been won is, in any case, impressive and, even at the present stage, has practical implications. It would be possible, for a beginning, to expatiate at length on the relatively crude type of experiment in which a man is shut up in a heat-recording chamber and fed with food of precisely calcu-

lated heat value. Provided he does not eat too much, his fuel consumption exactly balances his energy output, just as would be the case with a machine. Such a test is interesting enough in itself, but it is from the gradual exploration of the more complex mechanisms of the body that conviction will come if at all.

Pride of place may be given, at the moment, to the mechanism of heredity, although relatively little of our knowledge in this field has been derived from man himself, or even from any of the higher forms of life, in which breeding is slow and the influence of heredity correspondingly difficult to study. It was the obscure monk Mendel, working in his monastery garden at Brünn in Silesia, ignored by his own generation, who discovered the essential fact that heredity is atomic. By this is meant that all the individual qualities of any organism, from tallness to a capacity to do sums, are inherited from the generation which went before, in the shape of definite "factors", which the modern scientist calls "genes".

Mendel worked with pairs of contrasting qualities in garden peas, for example tallness or shortness and seed colour. One of his most important discoveries, both in the explanation of heredity and for practical purposes, is that both of such opposing qualities may be present in the same individual, the apparent result depending on whether the one quality was "dominant" or "recessive" compared with the other. Thus yellow seed colour proved to be dominant over green, so that individuals which inherited both qualities were indistinguishable to the eye from those that were "pure yellow". But they

none the less carried the germ of greenness within them, and he showed that there was a definite mathematical probability that this would come out in subsequent generations. In human beings brown eye colour is dominant over blue. Blue-eyed parents can never have brown-eyed children, but blue eyes may make their appearance in the children of brown-eyed parents.

This work of Mendel's is alone sufficient to give a general explanation of both the virtues and the dangers of inbreeding. The result of prolonged inbreeding within the same stock, in which the same recessive characters are unusually likely to be repeated, is therefore to bring out a large number of qualities which would normally be hidden. Provided that the individuals which show the unwanted hidden qualities can merely be weeded out, inbreeding is an admirable procedure. It is, of course, regularly used in the case of animals. With human beings the position is very different and, although cousin marriages may breed genius, the age-old tabu against marriages between closely related persons is, in the present state of knowledge, fully justified.

The difficulty is that there is no means of telling how many rare recessive genes may be lying dormant in the human race, waiting only for an opportunity to come together in the same individual to make their presence felt. If human heredity is ever fully worked out, it may be possible to tell which individuals carry what dangerous genes and to warn them against marrying together. At present it is probably wisest to play for safety. An interesting exception, which well illustrates the point that

inbreeding need not be dangerous if the stock is sound, is provided by the Pharaohs of Egypt. There, the rule of royal marriage was that the Pharaoh should marry one of his half-sisters. So far as history relates, there were no serious ill-effects, whereas if eugenic principles had been followed there would have been no Cleopatra.

Mendel also deduced that, however mixed the characteristics of a plant might be, its heredity factors were somehow sorted out or "segregated" in the reproductive cells which give rise to the next generation. That is why children, both in physique and mental qualities, are more than a mere blend of the corresponding qualities of their parents. They are the result, in a phrase familiar to-day, of a "new deal".

All this was as far back as 1865, although it was not until the present century that Mendel's work was rediscovered, the scope of his laws extended and made clear, and their physical basis explained. To-day it is known that the mysterious genes which Mendel studied are carried by a number of worm-like units, called "chromosomes", which are present in every cell of every living organism, and are the visible vehicles by which heredity is transmitted. In one case at least, these chromosomes have even been mapped out, so that it is known on which of them and in what order the different genes are carried.

A single glance through a microscope at the worm-like chromosomes in any of our body cells would probably not suggest that they had any connection with heredity. On closer inspection, however, it might be noticed that although they always numbered forty-eight, they could

be arranged in a series of like pairs, *AA*, *BB*, *CC* and so on, according to their sizes and shapes, so that the number of different kinds of chromosomes was only twenty-four. Further if the microscope was turned instead on to a reproductive cell, whether male or female, it would be noticed that there were in this case only twenty-four chromosomes instead of forty-eight, and that there was only one chromosome of each kind.

It is here that the secret of the heredity mechanism has been found. Out of any pair of chromosomes in a body cell, one comes from the male parent, and the other from the female. One, therefore, may carry a tallness gene and the other one for shortness, and that individual will be mixed so far as height is concerned. But that is only true for the body cells with their two sets of chromosomes. The reproductive cells, with their single set, must be either tall or short. So it is that between successive generations all the different characters which go to make up heredity are "segregated", only to be reblended when two reproductive cells are united to form the nucleus of a new individual. That is how Mendel's "new deal" is achieved.

So far, however, we have not been able to penetrate behind the gene-carrying chromosomes, to the genes themselves, the real atoms of heredity. This achievement stands mainly to the credit of Professor T. H. Morgan of America. His pioneer experiments at Columbia University have carried our knowledge a long way farther, and at the same time clearly illustrate another point of direct social importance. Professor Morgan works with

the fruit fly *Drosophila*, which feeds on rotting banana skins. This insect has two great advantages for the student of heredity. Its whole life extends over no more than a fortnight, and it has only four pairs of chromosomes. An almost unlimited number of generations can therefore be bred within the lifetime of a single experimenter, and it is relatively easy to decide which factors are carried by the same chromosomes. The latter type of deduction depends on the fact that certain chromosomes tend to stick together in the redealing process, so that one may be only exceptionally inherited without the others.

More important from the point of view of sterilisation is the discovery that a very large number of genes may be concerned with the control of a single physical quality. In the case of *Drosophila* more than fifty factors have to do with eye colour alone. It is evident that the heredity of such a complex creature as man is not likely to be easy to elucidate, and that a large number of genes may be necessary for the production of, say, a single type of mental deficiency.

This point has a direct and practical bearing on the various proposals which have been put forward for the legal sterilisation of defectives. From the examination of human pedigrees it appears that relatively few qualities are inherited on a simple Mendelian basis, that is through a single gene, and that this is certainly not the case with the great majority of mental deficients. A particular individual might therefore possess a group of genes which took him some way towards deficiency, but would yet have to marry a wife who carried the appropriate missing

genes before deficiency would appear in his children. If it is added to this that many of the genes in question are probably recessive, and so do not necessarily show themselves, it will be realised that the control of deficiency is far from easy.

This interpretation is strengthened by the fact that the great majority of defectives are unquestionably the offspring of sub-normal, not of mentally deficient parents. While therefore there may be something to be said for sterilising defectives as a measure of economy, this would be a futile policy from the point of view of reducing their numbers in the total population. The only advantage is that money need not be spent on maintaining them in an institution provided that they can be otherwise looked after, and this is an economic, not a scientific, argument. The whole lesson of any detailed study of human heredity is indeed that any drastic proposals for the improvement of the race, whether by sterilisation or eugenic marriage, should be viewed with extreme caution. Far too little is known of human heredity in relation to its obvious complexity.

It is probable, although the problem has not been worked out with the same certainty as in the case of *Drosophila*, that more than a hundred genes are concerned with human teeth, skin and eye colour alone. It is also probable that most physically measurable characteristics, height included, are affected by a large number of different genes, for the possible variations in all such qualities appear to be limitless. Relatively few conditions, including myopia and some forms of night-blindness and

deaf-mutism, are known to be inherited on simple Mendelian lines. But, beyond the commonsense advice that deaf-mutes should not marry, genetical science has little practical guidance to offer. Even this negative conclusion may be of some value when it is remembered with what immense enthusiasm eugenic control is even now sometimes advocated. Those who have religious objections to compulsory sterilisation may reflect that, for the present, science is on their side. When it has more knowledge, it may change its mind—in particular cases.

Yet if we regard heredity as one of the mechanisms of life, the position is very much more encouraging. Whatever the difficulties of detail, the statement is certainly justified to-day that the main basis of the whole elaborate mechanism of heredity has been made clear. Within the short space of the present century cases of Mendelian heredity have been worked out in practically every form of life from crustaceans to man. There is, therefore, good reason to believe that Mendel's laws apply to every species in which reproduction is bisexual. It has even proved possible, again in the case of *Drosophila*, to make some sort of estimate, not only of the positions occupied on the chromosomes by particular genes, but of their size as well. While the parts played by more than five hundred of them have been fully worked out, it appears that their total number must be more than eighteen hundred. On this basis their average length must be of the order of two-millionths of an inch, which is appreciably too small to be visible in the most powerful microscope.

On the other hand, in one particular type of cell, those

of the fly's salivary glands, it has lately been discovered that the chromosomes are greatly extended. If the heredity factors, strung out along the chromosomes, are correspondingly elongated, it is just possible that it may be practicable to observe them individually. In the meantime, although so much is known of their working, no one can put forward any real claim to know what they are. It only appears that they must be material entities of some kind. The explanation is not yet complete, but there is certainly no reason to believe that anything outside the ordinary laws of physics and chemistry will ultimately prove to be involved.

After heredity, the next great mystery of life is the power possessed by a single cell to divide and multiply into the whole variety of specialised cells which makes up the complete organism. It is perhaps the most extraordinary fact in the whole of biology that a single minute cell should have the power to turn itself in Shakespeare's words into "Item, two lips, indifferent red; item, two grey eyes, with lids to them; item, one neck, one chin and so forth", and even more surprising, if Olivia had not been solely concerned with her woman's beauty, into the human brain. Here, it might have been thought, if anywhere, was the point at which the merely mechanical processes of physics and chemistry must break down and prove inadequate. Yet it appears that the secret of nature's building process is nothing more romantic than a chemical.

In this case it was Professor Spemann of Dahlen in Germany who made the first vital discovery. He found

that a particular region of every embryo seemed to play the part of an "organiser" of growth, so that in an embryo which was deprived of its centre of development the different cells failed to differentiate in the usual way. Similarly, he found that, by grafting an additional organising centre into an embryo, the embryo could be made to duplicate many of its organs—so that twin-headed monsters could be reared analogous to the many-headed Cerberus of Hades. That was surprising enough, but now Dr Needham of Cambridge has made the further discovery that a chemical can be extracted from the embryos of newts which will itself act as an "organiser". It is not, however, yet known what this chemical may be, although something can be deduced about its nature. Still less is it known why any chemical should possess this power.

Next it is logical to turn to the maintenance and further growth of the body, once its different parts have been differentiated. Just as Professor Morgan's genes control heredity and Professor Spemann's organiser early development, so it has been found that the ductless glands control a large part of our later lives. Their activity also is chemical. The glands are in fact factories for the manufacture of specialised chemicals, called "hormones", within the body, and the blood stream the vehicle which carries the chemical messengers from these "general action" glands about the whole system. The thymus, which overlies the heart in young children, is connected with growth. It has been found that baby rats which are given thymus extract from calves develop more

quickly, the effect being cumulative if the same treatment is repeated in successive generations. Whereas normal rats grow their first hair when they are twelve to sixteen days old, the fifth generation of thymus-treated rats will show their first hair within two or three days of birth. This is one of the latest gland discoveries. It is due to three American research workers, Dr Rowntree and Dr Clark of Philadelphia and Dr Hanson of Faribault, Minnesota.

As the thymus disappears during puberty, its special function is evidently to control childhood growth. During this vital period, however, it is also assisted by two other glands, the prepituitary and the thyroid, both of which continue active into adult life. Nature's arrangements for growth control are therefore essentially complicated, although this perhaps was only to be expected. The task itself is obviously far from simple. Over-activity of the prepituitary makes giants, but this gland must be concerned with more than bone growth, for under-activity holds up sexual development as well as merely retarding growth. There is also no doubt that it remains important throughout life. If over-activity begins after maturity is reached, it stimulates an abnormal and unwanted bone growth in the hands, feet and skull.

The thyroid gland of the neck is connected with mental as well as physical development. A deficiency of the chemical which it produces results in the condition known as cretinism, in which a grotesquely childish appearance is retained into adult life, and mental development is completely arrested. But, although the thyroid gland is

also connected with growth, its most important function is the control of the body's chemical activity. A man whose thyroid is too active has a larger oxygen consumption and literally lives too fast. He may, as a result, show all the signs of nervous irritation. On the other hand, a deficiency of thyroid produces general sluggishness. It is here, perhaps, that the effect on growth comes in. If the chemical changes of a child's body are being slowed up, it is natural that it should be prevented from developing normally. There are therefore at least four directors of the various stages of growth and development—first Professor Spemann's "organiser", then the thymus, and finally the prepituitary and thyroid. There is much more to be learnt about the chemistry of growth, but it is no longer the complete mystery that it was.

In addition, there are two other glands which cannot be omitted from even the shortest account of this most important body mechanism. The chemical adrenin, produced by the adrenal glands near the kidneys, is of special importance to athletes. It makes all the necessary arrangements for any form of special physical effort. As well as speeding up the beating of the heart, it facilitates the blood flow throughout the body, slows down the irrelevant process of digestion, stimulates the supply of fuel to the muscles and urges the sweat glands to action. As a reminder of more primitive conditions, it even does its best to terrify the supposed adversary by causing the hair to stand on end and enlarging the pupils of the eyes. Finally, the pituitary has a real claim to be called the master gland

of the whole body for, in addition to various special functions of its own, it both stimulates other glands to greater activity and encourages the growth of their tissues.

As with heredity and the cell's "organiser", so also with glands, it is the mechanism, rather than the cause behind it that has been successfully explored. Only in two cases, those of adrenin and of thyroxin from the thyroid, has the product manufactured been isolated and made by the chemist in his laboratory. Yet the fact that this can be done at all is an indication that here also scientists are dealing with nothing supernormal, but that many of the body's most important activities are controlled by chemicals, all of which it will one day be possible to make and examine outside the body. The chemical study of the sex "hormones", which will not be here discussed, also points the same lesson. Even in these three examples—heredity, the development of the embryo, and bodily activity—science has already gone a long way towards removing the element of the unknown from the mystery we call life.

Finally there is one other line of progress which cannot be omitted from the balance sheet of knowledge and ignorance, that represented by the new knowledge which is being won of the working of the nerves, and even of the brain itself. Professor A. V. Hill of London has been the pioneer of the modern, quantitative study of nerve activity. He has found, for example, that an individual nerve can transmit about a thousand impulses a second with full efficiency and that the passage of each impulse is accompanied by a rise in temperature of between one

six-millionth and one eight-millionth of a degree—in itself an amazingly accurate feat of measurement. Visitors to his laboratory can also see the form of the electrical impulse which passes along the nerve. Both these changes are, however, regarded as no more than manifestations of something else, as yet undetected. It may well be that the fundamental change is chemical, but at present it is only known that the nerves, like the lungs, breathe in oxygen and breathe out carbon dioxide, and this in turn is no more than another way of saying that they derive their energy from burning.

The elucidation of nerve activity has also paved the way for the obtaining of electrical records from the brain, which was first achieved by Professor Berger of Jena and lately repeated and extended by Professor Adrian at Cambridge. The difficulty, and the obvious difference, is that whereas the nerves are relatively accessible, the brain is securely protected by a bony skull. For this reason it is not possible to observe the working of individual cells, although it seems that if the cells of a whole area of the brain are all beating in unison, the combined electrical effect is strong enough to be measured from outside. It has even proved possible, in a sense, to watch the brain working.

Professor Berger found that, when the eyes are shut, a regular electrical rhythm becomes established with a frequency of about ten a second. This rhythm may, however, be disturbed by concentrated thought, for example a mathematical sum which is difficult enough to demand the subject's whole attention. But there is no means of

telling whether the break is due to this cause or to the contemplation of a problem in philosophy, or indeed any other problem of equal difficulty. The rhythm which can be measured is that characteristic of a completely vacant mind. The waves are in a real sense brain waves, but they are waves of inactivity, not of thought.

From the extent to which the effect is localised, it is deduced that the area of the brain responsible is somewhere near the surface and is probably an inch or two across. There is also clear proof that it is connected with seeing. Although the rhythm can make its appearance when the eyes are open, it does so very much more readily when they are shut. Moreover, while it can be upset by thought, it can be very much more easily upset by the contemplation of any visual pattern. The explanation is probably that the brain cells only beat in unison when they are idle, and that the sort of things by which the rhythm is upset are a measure of the sort of activities, mainly centred in other parts of the brain, which are capable of affecting the part of the brain responsible.

Why can a regular rhythm only be detected from this one area of the brain? Professor Adrian's theory is that vision represents the one form of mental activity which can be turned on and off at will. In a special sound-proof chamber it might be possible to insulate the ears from all disturbance, but under normal conditions there can be nothing analogous to the insulation of the visual mechanism which is simply effected by shutting the eyes. One day, perhaps, it may be possible to watch, not the beating of brain cells in unison, but the activity of individual cells

or smaller groups of cells. Then scientists will really be able to watch the brain working and to record differences between the modes of thought of different individuals and even of races. It is not, perhaps, at the moment a very good hope. In the meantime there is the fascinating fact that thought can be detected by purely physical means.

So, one by one, the different mechanisms of life are being explored. In addition there is just one method available for testing the "mechanical" behaviour of the organism as a whole. The experiments of Professor Pavlov in Russia, designed to extend the scope of instinct as an explanation of apparently rational behaviour, are interesting in themselves, but contribute little or nothing towards the main problem. It is interesting to know that dogs, accustomed to the ringing of a bell as the prelude to their mid-day meal, will in time show the instinctive reaction of saliva to the dinner bell alone. Equally there are many human beings who are perfectly capable of working a typewriter without looking at the keys who would be quite unable to write down on paper the lay-out of the different letters. Long practice has made the necessary finger movements instinctive. It is not a good way of typing, but it does clearly illustrate the complexity of movement which can be undertaken without any active assistance from the brain. But as no one has ever ventured to deny that man is in part rational, however argument may rage about animals, the exact roles of brain and instinct are irrelevant to the present discussion.

Nature has, however, provided the biologist with cases

of so-called identical twins which, in so far as they may really be identical, provide a ready-made test of the extent to which a man's behaviour is determined in advance by heredity and environment. These are twins which are formed by the splitting of a single ovum, so that there should be no difference between their hereditary constitutions. That, at any rate, is the theoretical explanation of the very strong similarity which exists between twins of this type. The simplest, though inadequate, definition is that they are the sort of twins that the ordinary friend of the family finds it difficult or impossible to tell apart. Most people probably know one or two examples. Often, if they go to the same school, they can be watched ascending form by form in company, obtaining their colours at the same sport at the same time, one perhaps slightly more able than the other, but generally speaking, pursuing strictly parallel careers.

Professor Dr Johannes Lange has attempted, in Germany, to translate such familiar parallelisms into a scientific thesis. He took the trouble to collect the life-stories of thirteen pairs of such twins, at least one of which in each case was a known criminal. The careers of nine out of these thirteen pairs were so closely identical as to justify, in the opinion of Professor J. B. S. Haldane, the belief that their behaviour could not be regarded as determined by their own "free-will". Even Professor Haldane, however, admitted that free-will might "very occasionally tip the balance over, and thus count for something in the long run", and the average biologist is very much more cautious than that. The plain fact is that experiments of

this kind are logically inconclusive and must inevitably remain so.

The experiment is, in fact, one of tantalising possibilities. If it were practicable to provide the two halves of the split ovum with identical environments from fertilisation throughout life, and yet exclude mutual influence, then a completely cut-and-dried test would be possible. In real life these conditions are not, and can never be, satisfied—nor is it possible that the careers of two twins could ever, in the strict sense of the words, be identical yet independent.

At the most, therefore, it can only be claimed from Dr Lange's experiment that the main lines of a man's life are more closely determined for him by heredity, upbringing and circumstance, and less by any freedom of action of his own, than is generally realised. Or pointing the way of escape, it might be said that if he were capable of making a different choice he would not be the same man. In any case it may be doubted if any community would ever agree, whatever the evidence, to forgo the legal and social sanctions with which it seeks to control the behaviour of its members. Whether or not crime is, as Professor Haldane believes, destiny, there can be no doubt that the fear and example of punishment must be numbered among the environmental circumstances which, in many cases at least, must exert a controlling influence on man's life.

The problem is therefore in the main one of philosophical importance, and politicians will not worry unduly if it is never solved. The same cannot be said of another

problem, which Professor S. G. Levit in Russia is attacking with the aid of a hundred pairs of "identical" twins. In effect he has turned Dr Lange's method exactly inside out. Instead of seeking for pairs of twins with identical careers, Professor Levit's aim is to make their careers as different as possible by education. Giving each of two twins a different type of education, he will be able in the long run to compare the results with confidence. Moreover he will never be short of material, for he can secure that any pair of twins in the whole of Russia can be sent to his school, and once there he can do with them exactly as he likes.

It is a line of attack which should answer a number of questions which are socially important. In England, for example, it would be generally agreed that the average public schoolboy, even allowing for those who fail to secure entry, was more intelligent than the average boy who follows the normal round of state-provided education. The emphasis in each case, it should be pointed out, is on the word "average". But how far is this superiority due to the presumed greater intelligence of their parents, as indicated by their having so far succeeded in life as to be able to afford an expensive education for their children? How much higher, looking at the matter from the opposite angle, might the average standard of the country have been if every child had been brought up under similar material conditions and with the presumed stimulus of educated surroundings? How far, in fact, can the mental standards of a country be raised by improved opportunity?

It is a question in which future Utopias will be greatly interested. Experiments such as Professor Levit's should provide the answer, just as they should also show which types of education are most suited to which types of children. Only so can the same child be educated, so to speak, twice over. It is a unique opportunity, but it is difficult to see how in any other country but Russia it can be adequately exploited. Numbers are essential, and in spite of an interesting experiment in America, it may be doubted if adequate numbers can ever be voluntarily secured. In the meantime Professor Hogben of the London School of Economics and Dr K. J. Holzinger of Chicago, among others, have performed a valuable service by measuring the extent to which "identical" twins, who have been normally brought up, give identical scores in intelligence tests. Whereas fraternal twins are roughly 50 per cent. alike, it appears that the percentage of community rises to about 85 in identical twins.

There remains for discussion one other question of obvious practical importance, as it was put at the beginning of this chapter, "Is heredity something which is fixed, or may the benefits of training and education be passed on, in part, from one generation to the next?" To the biologist it is merely the old controversy of the "inheritance of acquired characteristics" which was started more than seventy years ago by Darwin's somewhat grudging conclusion that this might be one factor in evolutionary change. To the sociologist the question raises the whole issue of human progress. If characteristics acquired during life can be inherited to any

extent at all, then inventors and statesmen, and to a lesser extent every separate individual, have the unconscious power of moulding human evolution. If we are car-minded, our remote descendants should in the course of time become hereditarily better equipped for the avoidance of street accidents. If we study Einstein with sufficient zeal, remote generations should grapple more easily with relativity. If we persevere with general education, then the general standard of intelligence should, in the long run, be automatically raised.

The most famous experiments by which any scientist has attempted to solve the problem are those undertaken on the training of rats by Professor William M'Dougall of Duke University. For more than fifteen years now Professor M'Dougall has been breeding rats from the same stock and watching their progress in his aquatic school. Some forty generations of rats have so far been bred by him. Those of each generation have been systematically placed six times a day in a water tank from which there are only two ways out—one by a platform which is lighted and administers an electric shock, and the other by a platform which is unlighted and gives no shock to the escaping rat. The test consists in observing the number of mistakes made by successive generations before they learn their lesson.

His conclusion is that long breeding quite definitely produces an improvement. For example, the best rat of the thirteenth generation made thirty mistakes before learning the proper way out, while the best rat of the thirty-fourth generation made only two mistakes. One

criticism put forward at an earlier stage was that the mother rats might perhaps be teaching their young about the dangers of the lighted platform, just as observation suggests in the case of birds that the young are sometimes warned by their elders of impending danger. This suggestion Professor M'Dougall met by taking some of the young rats away from their parents at birth and having them reared by rats which had been given no experiences of the kind. Another criticism which has been advanced is that some unsuspected form of selection may be at work, although this could scarcely explain the rising standard of ability shown by the best rats. On the other hand Professor F. A. E. Crew, Director of the Institute of Animal Genetics at Edinburgh, has not, after six years of similar tests, been able to report any tendency towards improvement. He does, however, find that rats share a very human dislike for brain work in the early morning.

Another English scientist, Professor E. W. MacBride of London, who is one of the firmest believers in the inheritance of acquired characteristics, has carried out an entirely different series of tests on the diet of stick insects, which are imported from India by dealers and are normally fed on privet. This insect produces eggs which develop without being fertilised by the male, and give rise to females like the mother. The advantage of this arrangement to an experimentalist is that each young insect is merely a new edition of its only parent, so that there can be no unwanted variations in the stock during the course of the tests.

Professor MacBride's assistant, Miss Sladden, found that although these insects originally disliked feeding on ivy leaves instead of their usual privet, they could be forced to do so by what amounted to starvation. Each insect was reared in a separate box and, if it refused to take ivy for two days, it was revived by being fed on privet for one day, after which it was again given ivy. Some insects had to be "revived" ten times before they would eat the hated ivy. In the end they all did so and, as in Professor M'Dougall's tests, they learnt their lesson significantly more quickly in successive generations. Further experiments will, however, be necessary before the conclusions which Professor MacBride draws are generally accepted.

Even more definitely does the problem of life itself still defy solution. Progress has been rapid and impressive, but from its nature is confined to the exploration of particular mechanisms one by one. Sufficient has been said to show that many of the issues raised are of practical importance. Ultimately it may prove possible to build up the whole into a single picture in which no other factors are invoked than the known laws of physics and chemistry. That day is yet a long way off. Indeed it is difficult to see how, in such a complicated field, finality can ever be reached. There is a school of thought, represented by Professor J. S. Haldane, which believes that life itself will never be analysed. The whole, he suggests, is so much greater than the parts that it will never be fully explained in terms of them. On the other hand, the majority of working biologists hold to what is still most

briefly described as the materialistic picture. Perhaps the only final criterion will be the creation of life in the laboratory. If ever it is shown that life may arise spontaneously, under given chemical and physical conditions, then it must follow that life is amenable to the ordinary laws of physics and chemistry.

CHAPTER X

THE RIDDLE OF SEX

WHY are some of us born boys and others (roughly an equal number) born girls? These are questions which have given rise to hope, envy and despair since the world began. Parents from Old Testament times onwards have longed to control the sex of their offspring. Yet in no single case is there any serious evidence that they have succeeded. Even at the beginning of the present century it was believed that boys and girls started life alike. Sex was supposed to be determined as the embryo developed, and as nothing was known about the factors which might affect development, there was infinite scope for superstitious belief. At the same time elaborate tables were prepared purporting to show at what periods in a woman's sex cycle she was most likely to conceive a boy, and at what periods a girl. Other attempts have been made to link sex with the physical condition of the woman at the time conception takes place. But though kingdoms have fallen for lack of a male heir, none of these efforts have yet survived the hard test of statistics. No matter what the treatment, the proportion of the sexes has never been significantly altered.

To-day science provides, on the one hand, a clear picture and on the other a medley of still unresolved doubts. But

at least there is a picture, even if it seems to some critics that it is too simple to be fully true. For the future, it is only possible to guess at the lines on which some of the prevailing uncertainties may be removed. There is no doubt that the mystery of sex, now only partly understood, will one day be completely unravelled. There is also a possibility that the control of sex may become feasible—more probably in animals, perhaps also in human beings. More than that cannot be said.

For the clear, but maybe only partially correct, picture science is indebted to the microscope, which has yielded so much other knowledge about the human body. Reference has been made in the preceding chapter to the fact that hereditary characters are carried by minute worm-like units in every cell in our bodies. The microscope shows that in every form of life these can all be arranged as a series of like pairs—*AA*, *BB*, *CC* and so on—with the important exception that there is one pair which though like in one sex is unlike in the other, say *XX* and *XY*. In man and in mammals generally, it is the males which have the unlike pair, and the females the like pair. But there is nothing universal about this arrangement. In birds it is the other way about. The males have the like units, and the females the unlike.

The supposed mechanism of sex inheritance depends on the fact that, alone of all the cells in the body, the reproductive cells carry only a single set of heredity-bearing units. Every ovum (female reproductive cell) therefore carries a single *X* unit, and is identical with every other ovum. But a sperm (male reproductive cell) may carry

a single X unit or a single Y unit. The sex of the prospective infant should therefore depend on which of these two types of male cell happens to engage in fertilisation. An X sperm must, it would seem, produce an XX child, that is a girl; and a Y sperm an XY child, that is a boy. That is the simple picture. It is the basis of the belief that sex is determined at the moment of fertilisation. It also implies that in man, and indeed in all mammals, it is the male who determines the sex of his children. No husband, it appears, has any right to blame his wife for presenting him with a long string of girls. The fault, if it can be called a fault, is his own. On the other hand, a chicken farmer who finds that his hens will keep on breeding cockerels, when he wants more hens for laying, is perfectly right in putting the blame on the hens. The cock, which has been responsible for fertilisation, has had no part in determining the sex of his chicks. It may seem hard that the responsibility should in each case be one-sided. But the arrangement, like most arrangements of nature's devising, is by no means a bad one. It represents probably as simple a mechanism as could be devised for ensuring the rough numerical equality of the sexes. "Male and female created he them." But, failing outside interference, the sex of all subsequent generations was left to the unerring guidance of a strictly even chance.

There are, however, a number of indications that the matter is not quite so simple. For example, it is a fact which still awaits explanation, that there was a slight but definite increase in the proportion of male children born in all the principal belligerent countries during the War,

except Italy. Whereas in Germany, during the eight preceding years, 1055 boys had been born for every 1000 girls, the wartime proportion rose to 1068. In England the corresponding rise was from 1039 to 1048, and in France from 1045 to 1054. There was also a perceptible rise in the Netherlands, the neutral country most closely affected by the War, from 1051 to 1059. The increase does not perhaps seem very big. But it must be remembered that a four years' total of births represents a considerable figure in any of these countries. An increase of the order of one per cent. in the proportion of male births is therefore quite big enough to demand explanation.

With the belligerent nations thinking in terms of man-power, it might appear that the male increase was merely an example of the mass victory of mind over matter. Mothers, it might be argued, with no certainty that their husbands would come back to them, longed with special urgency for men children—and on the average their longing was gratified to the slight extent already indicated. This is not, however, the sort of suggestion which is likely to be accepted by scientists without very good proof. It is much more probable that physical conditions during the War years were responsible for the sex difference. Food shortage was the most obvious and universal change. Is it fanciful to see a possible connection with the known fact that the sex ratio of the flour moth is altered by partial starvation of the larvae? The normal proportion is 61·6 per cent. males to 38·4 per cent. females. Two days of partial starvation result in the proportion of 46·4 per

cent. males to 53·6 per cent. females. The change is in the opposite direction, from males to females. But the essential fact is that physical conditions during an early stage of development have altered the sex ratio. The coincidence is at least suggestive.

The frogs of Northern Europe may be used to illustrate another type of difficulty. In their case the young frogs which emerge from the water are in the proportion of nine females to every male. Here, it might seem, was a clear case for polygamy. Yet in the course of their growth to maturity, four out of the nine females turn into males; so that, in the end, out of the original ten frogs, five will be male and five female. It seems that in the frogs which change their sex, sperm-producing cells are formed from the covering of the ovary. These grow and invade the ovarian tissue until ultimately all the eggs are destroyed. The animal then becomes a male, the growth period having occupied four years.

Similar inversion of sex has been recorded in the case of hens, up to the point of parenthood in the new sex. In a famous hen, owned by Professor F. A. E. Crew of Edinburgh University, the change was produced by a tuberculous growth. This hen was an elderly bird, which for several years had laid eggs from which chicks had been hatched. There was therefore no doubt about its sex. It was a mother several times over, and no doubt fully as maternal in its behaviour as any normal hen. Then it began to become aggressive. Spurs sprouted from its legs, and a cock-like comb from its head. It took to heralding the dawn with a full-blooded crow. Finally,

n its new capacity of a male, it proceeded to fertilise the ɜggs of other hens. Not until the hen had died was its ;ecret discovered. It was then found that its ovary had ɔeen destroyed by tuberculosis, while from the covering ɔf the ovary a male gland had been developed.

The opposite change is relatively common in crabs. But in their case it is due, not to disease, but to a parasitic ɔarnacle, which spreads its absorbing roots through their ɔodies and lives on their blood. So long as the parasite ives, the growth of the crab is stopped. But when, after he lapse of a year or two, the barnacle dies and drops off, he crab resumes its growth. When this happens, it is ound that male crabs have been transformed into females. Similar, but never complete, inversions have also taken ›lace in the case of mammals, and even human beings. Such cases are from time to time reported in the press. They are often of considerable interest scientifically, but ι natural reluctance to discuss physical details inevitably esults in a false impression being given. A moment's eflection will suggest that a complete inversion of sex in : human being would be little short of miraculous; and, n point of fact, it is highly improbable that such an inversion has ever taken place.

Another type of complication is represented by what re called secondary sex characteristics. The comb, which Professor Crew's hen grew, and its capacity for crowing .re obvious examples in the case of a fowl. But such lifferences go much deeper than mere external features. t needs no scientist to tell us that they extend even to nodes of thought. A woman's quick wit is no figment

of the male imagination. It is a truism that women depend, on the whole, more on intuition and feeling in their judgments than do men. No doubt this is to a large extent the explanation of both their greater quickness, and as men would say, of their inconstancy. But what is much more important is that these secondary differences between men and women pervade their whole bodies. They are due apparently to two substances, which are manufactured in the sex organs and pass out into the blood stream. Recently both these substances, known as the sex hormones, have been isolated and their chemical constitution determined.

Modern knowledge of the sex hormones tends, on the whole, to reinforce the lesson taught by those cases of natural inversion of sex which have already been described. In the case of horses, for example, it has been found that stallions actually produce larger amounts of the female hormone than do mares, even under the most favourable conditions. From these and other observations the conclusion seems inevitable that the female hormone is by no means the exclusive prerogative of the female sex. May it not be the case that sex is never wholly cut-and-dried? There are plenty of both effeminate men and masculine-minded women. It is a mistake to regard such people as being, in any definite sense, abnormal. It is probably far more true to suggest that every man is to some extent a woman, and every woman to some extent a man. The difference is most likely, so far at least as secondary characteristics are concerned, to be one of degree.

The general conclusion to be drawn from an impartial

survey of the facts seems to be this. Every fertilised ovum starts life with the potential ability to become either a male or a female. But it also receives at fertilisation, on an even chance basis, a definite and in most cases decisive tendency to develop as a member of one or other sex. According to this view sex is determined, in general, at fertilisation. A tendency to maleness will normally produce a male. But the potentiality of femaleness will still be there. In relatively simple forms of life, in which sex differentiation has not proceeded too far, complete inversion may be possible in after life. In other cases, such as human beings, complete physical inversion is an impossibility. But partial inversion is possible, although rare, and some mixing of secondary sex characteristics the general rule. It does not follow that human sex is absolutely determined at fertilisation. But it does seem that if the sex of an embryo baby ever undergoes change, it does so at a very early stage of its development.

How is the problem of sex determination affected? It will be already obvious that the control of sex is no easy matter. We may probably accept as a start that the female ovum has nothing to do with the sex of the offspring produced, while the male sperm most certainly has. This is admitted even by those biologists, such as Professor E. W. MacBride, who hold that sex is not wholly determined by the heredity mechanism. But it does not take us much farther. One of the few certainties is that male- and female-producing sperms must be produced in equal numbers, so that the individual ovum has, so to speak, the choice of a very large number of both kinds of sperm.

It is one of the paradoxes of nature's reproductive methods that, although the male determines the sex of the offspring, he cannot control it.

Provided that nature's method is retained, there is one hope, and one hope only, of controlling the sex of our offspring. It is that some physical condition of the woman makes fertilisation with one kind of sperm more probable than fertilisation with the other kind. It is perhaps not a very good hope. Certainly it would never have been put forward even as a speculation, but for the accidental discovery in Germany that a cow, which had been given heavy injections of bicarbonate of soda proceeded thereafter to calve nothing but bullocks. This may, of course, have been coincidence. There are plenty of human mothers whose children seem fated in advance to be boys; or who, more commonly as it seems, concentrate exclusively on girls. The probability is, in fact, that of every 32 women with families of five children, one will have five boys and another five girls. It should not be humiliating to reflect that the probability in the case of a cow is exactly the same. None the less the observation drew attention to the possibility that the alkalinity of the mother's blood might have some effect on the sex of her offspring. It may be true—or it may not. At any rate several doctors are experimenting on these lines. All that they can do is to persuade those of their married patients who want a child of either sex to accept their advice, and record the results obtained. Naturally it is a slow business, and not until a thousand or so cases had been tabulated would it be obvious if any success was being achieved. At

the moment the theory on which their work is based can only be classed as an intriguing heresy. It may represent the whole truth, or half a truth, or no truth at all.

There is, however, another line of approach. In many cases of male disability, it is possible to produce perfectly normal children by artificial insemination. From the male the surgeon secures a supply of sperm-containing fluid, and with it inseminates the woman. The resulting child is then, in every sense of the word, his father's son. He is grown from a normal sperm and a normal ovum, and the only difference is that nature's method has not been followed. Is it possible that married couples who keenly felt the want of a boy or girl, as the case might be, would accept such a procedure, provided that the sex could be guaranteed?

From many people the reply would be an emphatic negative. The problem is, in any case, not one of urgency. It is merely suggested as a practical possibility by the work of two Russians, N. K. Koltzov and V. N. Schroder. These Moscow biologists claim to be able to separate the male- and female-producing sperms of the rabbit by physical means. They say that the male-producing cells bear a positive electrical charge, and the female-producing cells a negative charge. They also make the further claim that they can control the sex of baby rabbits with fair certainty by inseminating a female with the separated sperm. What are we to make of these claims? At present an insufficient number of tests have been reported for any valid conclusion to be drawn, and in any case the answer

can only be provided by further and more general experiment.

There is at least nothing impossible in the idea. The microscope shows that the two kinds of sperm are different, and where physical differences exist, it should always be theoretically possible to bring about physical separation, even if the process is a long and difficult one.

What would be surprising would be if the relatively small difference between male- and female-producing sperms were represented by such a marked difference in physical properties as that claimed by Koltzov and Schroder. The cells of a rabbit include more than forty heredity-bearing units. All but one are alike in both kinds of sperm. Is it likely that this single difference is going to cause such a marked change in the cell's physical properties as the reversal of its electric charge?

Once again we must conclude with a question mark, although the question mark can in this case be followed by a footnote representing more or less definite probabilities. Sex is primarily, but not necessarily completely, determined by the maleness or femaleness of the sperm cell which happens to fertilise the ovum. Under natural conditions the hereditary determination of sex is therefore a matter of chance which it is unlikely, although not impossible, that man will be able to influence. Only if the male- and female-producing sperm cells can be separated is it likely that sex will become controllable. It may, or may not, be thought worth while. The business of science is to provide the knowledge and the power.

CHAPTER XI

NATURE'S BUILDING BRICKS

To unify is to some extent to understand. It is indeed the whole purpose and method of any form of scientific enquiry. It may be true enough, as any car driver will agree, that no two cars which have ever been turned out are exactly alike. Yet the statement that a particular car is a "Morris Minor" or a "Ford Straight Eight" does convey at least a large part of the information which a prospective purchaser requires. So it is in the natural world. Nature does not repeat herself. But she uses standardised components—a great deal more accurately standardised than those of any car manufacturer; and she puts the different components together on recognisable principles. There are, in fact, only a limited number of building bricks, of which everything in the universe is built up. There is no scientist living who would to-day dispute this. Yet it is by no means certain how many kinds of building brick nature uses, or what the different bricks are. That is the unsolved problem of nature's building bricks. It may seem academic, remote from ordinary life. Yet in this chapter we shall be discussing not only what we ourselves are made of and our friends, but what the earth is made of and the stars, and even the smoke that is rising from my pipe as I write.

The very complexity of the material world is a powerful

incentive to reduce it to simpler terms. A visitor to a geological museum may notice some lumps of grey rock and learn that they are one kind of iron ore. If he happens to be carrying a pocket compass he will know in advance that this also is made of iron—although, unlike any other kind of iron, it always points at the North Pole. Afterwards his doctor may tell him that there is not enough iron in his blood, although there is nothing to suggest, at first sight, that his blood has anything in common with, say, a carving knife. The mere statement that there is iron in each of these things represents an important advance in knowledge.

For more than two thousand years man has been attempting to unify his knowledge of matter, and is still trying to do so to-day. One of the first attempts was the classification, adopted by Aristotle, into earth, air, fire and water. It is probable that Aristotle regarded these four elements as representing qualities in terms of which matter could be classified, rather than as "elements" in the modern sense. But this cannot be said of Plato who, in one of his dialogues, expressed the serious belief that "earth" was built of cubes, "air" of regular octahedra (solids with eight faces), "water" of icosohedra (twenty-faced solids), and the human body of triangles.

Here was an unusually definite form of atomic theory. That it sounds to-day like arrant nonsense is merely a measure of the progress which has been made. Plato, after all, was right on the main point. He believed that all matter was built up of a limited number of components, and his belief stands justified. The chief difference is that

what modern scientists know they know from experiment, and what they do not know they admit frankly. Moreover, until the end of last century, the trend of experiment was on the whole away from any such simple theory of matter as Plato's, so that a return to comparative simplicity is all the more impressive.

During the course of the last century the four elements of the Greeks gave place to the ninety-two elements of modern chemistry. It was learnt also that, although nearly all of these elements could form innumerable "compounds" with other elements, the elements themselves were chemically immutable. Thus lead would combine with sulphur to form "galena", with the oxygen of the air to form the "red lead" of pottery glazes and red paint, and would dissolve in a number of different acids, to form a corresponding series of "salts". But nothing that a chemist could do to lead would turn it into gold or indeed any other chemical element. Here was a sad relapse from the dreams of mediaeval alchemists who, following the Greeks, believed that there was no insurmountable barrier between one metal and another.

It was also learnt that each chemical element was made up of units called atoms, which it was believed were all alike for any given element. Thus all the atoms of lead were supposed to be identical, and so on for gold, silver, iron and all the other elements. The atom was therefore the smallest unit which could take part in chemical change. So far the theory was, in the main, sound and well-substantiated and, if one thing seemed more certain than another, it was that "transmutation" was impossible.

However, as the atom could by definition never be split by any chemical means, the chemist could hope to make little further contribution to its study. He could only notice one or two ways in which the properties of atoms, as he met them in his laboratory, suggested some underlying unity.

He could notice, for example, that the weights of many different atoms were nearly exact multiples of the weight of the hydrogen atom. This suggested, although it did not prove, that they might be made up of a number of hydrogen atoms in closer combination than any chemist could produce. He could also notice that, with a few exceptions, all the known chemical elements could be arranged in a "periodic table" according to the weights of their atoms, the properties of different elements being more or less reproduced after definite intervals. Why, the chemist began to ask, should there be relationships of this kind, if all the different atoms represented independent building bricks? But all this was merely suggestive, and there were difficulties in the way of either train of reasoning. The clue could only come from the atom itself, that is from outside chemistry.

The new physics, which was quickly destined to replace chemistry as the main source of information about the atom, began in effect with the discovery of X-rays by Professor Wilhelm Röntgen of Munich, just five years before the turn of the century. It is perhaps worth mentioning that, unlike the great majority of really important scientific discoveries, it was a pure accident. Professor Röntgen happened to have lett some photographic plates

near an evacuated glass tube through which he was passing an electric discharge. He happened also to notice that the plates were fogged, although they appeared to be well protected against light. So it was that X-rays, which can pierce any screen but the thickest lead, were discovered.

Important as X-rays have proved in medicine, they have played an even more important role in scientific progress. It was not so much that they themselves gave any new information about the atom as that they stimulated enquiry. The discharge of electricity through a gas under low pressure had, for example, already received some attention. But it seemed to most people, as indeed it sounds on paper, an unpromising subject. In fact, however, it had led to the discovery of X-rays and so, presumably, was worth further enquiry. The result, a matter of two years later, was the discovery that the flow of electricity through a vacuum tube was neither more nor less than a stream of what we now call electrons from one end of the tube to the other.

This was the beginning of the now classical exploration of the atom in the Cavendish Laboratory at Cambridge. It was there that J. J. Thomson, now Sir Joseph Thomson, succeeded in measuring both the weight and electrical charge of these new particles. His most vital discovery was that the weight of the electron was of the order of a thousand times less than that of the hydrogen atom, itself the lightest of the atoms. More accurate measurements show that it is 1838 times lighter. At once the possibility arose that all the different kinds of atom might themselves be built up of simpler components, and within four years

of the discovery of X-rays "J. J." was already suggesting that the electron might be a natural and normal constituent of all matter. He also found that his electrons were negatively charged, and that the charge which each bore was identical with the smallest unit of electricity ever carried by any liquid particle. It seemed, therefore, from another point of view, that the electron was the fundamental unit of electricity, so that matter and electricity were already linked.

At the same time the search for a natural source of X-rays led to the discovery of radio-activity by the French scientist, Henri Becquerel. So the ripples spread out from Röntgen's unintentional exposure of a photographic plate. Radio-activity has itself a double significance in the story of the atom. It provided in the first place an entirely unexpected example of the atoms of an element breaking down of their own accord and turning, in the process, into atoms of quite a different element—in fact, into lead. This was in itself an incalculable stimulus to the new picture of the atom as being made up of more elementary particles. It was not exactly transmutation, for the process could not be controlled. But it made transmutation possible, for the high speed particles thrown out by radium and other radio-active elements were to provide the projectiles with which Lord Rutherford could knock ordinary stable atoms to pieces and for the first time turn one element into another—at will.

Germany, France and England therefore each played an important part in the first stages of the exploration of the atom. Without going farther into historical detail,

it may be remarked that the original technique of atom-splitting still holds good. Practically all knowledge of the atom has been obtained by bombarding it with fast-moving particles and by recording the speeds, weights and electrical charges of the particles which it throws out. The only difference is that, instead of relying on radium for their ammunition, scientists now provide their own. Omitting, therefore, all details of discovery, we may now take a glance at the picture of the atom which would have been almost universally accepted only four years ago. We shall then be in a better position to appreciate the revolutionary nature of two or three new discoveries which have once again made the number and variety of nature's building bricks an unsolved problem.

To the light and negatively charged electron there was first of all added the heavy and positively charged "proton", which is neither more nor less than what remains of a hydrogen atom when its one electron has been taken from it. It is in fact the "nucleus" of the hydrogen atom, the lighter electron being pictured as revolving round it as the moon does round the earth.

All other atoms, it was thought, could be built up from these two units, the final result being not unlike a miniature solar system. The resemblance is two-fold. The simile suggests in the first place that the atom is to a large extent empty, and that it is likely to be about as difficult to score a direct hit on any part of it as it would be for some far-distant marksman to shoot projectiles at the solar system in the hope of hitting either the sun or one of its planets. Experience shows that the chances of securing a direct hit

are not very dissimilar in the two cases. This, incidentally, is why atom-splitting is never likely to be an economic method of obtaining cheap energy for industry.

The atom's second resemblance to the solar system is that by far the greater part of its weight is at the centre. But, unlike the sun, the nucleus of an atom is pictured as being itself complex. According to this four years old picture, the nucleus of any atom was supposed to consist of a number of protons (heavy and positive) and a smaller number of electrons (light and negative). The nucleus was therefore, on balance, positively charged. The planetary part of the atom, on the other hand, was given no heavy particles at all, but merely a sufficient number of electrons to counterbalance the positive charge of the nucleus.

That then, with a certain amount of mathematics omitted, is the picture of the atom which any physicist would have given only four years ago. So far as the outer electrons are concerned, and their general relationship with the nucleus, it still holds good to-day. For our present purpose, the main point is that no kind of atom was supposed to contain anything else but protons and electrons, and that matter and electricity were inseparable.

How far was this picture satisfactory? Objectively, it must be admitted, it explained a great many facts about the atom extraordinarily well. It explained, for example, why the different chemical elements fell naturally into a series of groups; why atoms should combine together to form chemical compounds in the proportions they do

(e.g. two atoms of hydrogen to one of oxygen, in water); what happens when radium breaks down; and how atoms become electrically charged. But, as the greater part of an atom's normal behaviour is determined by its outer electrons, most of these practical achievements were independent of any surprises which the nucleus might still have in store. Actually it has been discovered that there is a great deal more in the nucleus than was originally supposed.

Intellectually the picture of all matter as being made up of protons and electrons was far from satisfying. Indeed, in the light of recent events it seems almost surprising that it was so long accepted as final. We have no right, of course, to suppose that nature's arrangements must necessarily conform with man-made ideas of symmetry. But even making due allowance for our natural conceit in such matters, the proposed arrangement must appear more than a little extraordinary. The charge which a proton bears is, it will be remembered, equal and opposite to that carried by an electron. Moreover, there is nothing in electrical theory to suggest that there is any necessary distinction between positive and negative electricity except that of "oppositeness". Yet here we are given units of positive electricity and units of negative electricity and told that they are alike in all other respects except that the positive units are 1838 times as heavy as the negative units. It might have been so—but it would have been odd.

The business of science, however, is not to build up aesthetically satisfying pictures, but to take the world as it finds it. The experimental evidence was clear. Heavy

protons had been found in the nucleus of different atoms, and so had light electrons. The discrepancy had to be accepted, and this acceptance of observed fact was never more evident than at the Bristol meeting of the British Association in 1930, when Dr (now Professor) P. M. Dirac, a then unknown Cambridge mathematician, astonished the scientists by presenting a brand-new mathematical interpretation of matter. One result of his theory was that it accounted for the existence of particles of positive and negative electricity, and that it allowed of the combination of weight and electricity in the same particle—as is the case in both the proton and electron. But, and this was the chief difficulty in Dr Dirac's theory, the positive and negative units should have weighed the same.

Had he possessed the courage to stick to this conclusion, in the face of what then seemed to be the facts, Dr Dirac might, as we shall see later, have made one of the most successful predictions in the whole history of science. As it was, he did what almost any other scientist would have done in the circumstances. He accepted the findings of his laboratory colleagues as correct, and expressed the pious hope that the discrepancy between his theory and the facts would one day be removed. His hope was duly fulfilled. But it was the theory, and not the "facts", which was correct. This is, however, anticipating. The episode has only been related at this stage in order to illustrate that, mathematically as well as in common sense, there is a difficulty in the 1838-fold discrepancy between the masses of the proton and electron.

The first invasion of the hitherto undisputed domain of the proton and electron came with startling suddenness from the Cavendish Laboratory a matter of two years later. The scientist responsible was Dr J. C. Chadwick, who up to that date had been notorious in the laboratory for the bad luck which had persistently dogged him in research. As a prisoner of war in Germany he had devoted himself to one of the few lines of research which he could carry out with the limited apparatus at his disposal. When peace came, he returned to England with the feeling that the long years had not been wasted and every intention of publishing his results. But with scientific journals again at his disposal, he found that he had been forestalled. The long years had been made more interesting—but the pride of discovery had gone. It was so, in the main, at Cambridge. Then he read of some research carried out in Paris by Irene Curie, the daughter of the discoverer of radium, saw a glimmering of new light, and leapt to the attack. Within a few weeks he had proved the existence of a new kind of atomic particle, the first addition to nature's building bricks since the recognition of the proton and electron more than twenty years earlier.

The new particle was christened the "neutron", because although it was heavy like the proton, it possessed neither a positive nor a negative charge. Its advent caused more of an upheaval in the world of physical science than any discovery since the original splitting of the atom by Lord Rutherford. Not only had the neutron the spectacular appeal of being the most penetrating of known particles,

a distinction which it owed to the absence of electrical charge. It also raised anew the whole thorny question of the relation between mass and electricity, which everyone thought had been decently settled. The difficulty, in a nutshell, was that the neutron appeared to have the same amount of matter in it as the proton, in other words it weighed the same, yet it was electrically different. Weight and electrical charge must once again, it seemed, be regarded as independent entities.

The next upheaval came two years later and was jointly due to two scientists, working quite independently in different countries. At Pasadena in the United States Dr Karl Anderson obtained some photographs of particles which, although of the same order of weight as the electron, appeared to be positively charged. He suggested that they might be "positive electrons". At the same time, in England, Mr P. M. S. Blackett (now Professor Blackett), who was then working at the Cavendish Laboratory, was obtaining similarly unexpected photographic records. He had many more photographs than Dr Anderson possessed at that time, and his records were very much nearer to being conclusive. But as Dr Anderson was the first to publish his results, the credit of priority is deservedly his.

Here, then, was the "positive electron", immediately shortened into "positron". Both in England and America the positron was first discovered in cosmic rays, the mysterious radiation from outer space discussed in an earlier chapter. Even had this been the only source of positrons, scientists would still have had to

explain their existence. But in point of fact positrons were soon extracted in perfectly ordinary laboratories from perfectly ordinary atoms, and it was early agreed that the positron must be accepted as a normal constituent of atomic nuclei. Indeed, once the positron had been discovered, the chief wonder of scientists was that it had not been detected before; and the chief wonder of Dr Dirac that he had not been bold enough to predict its existence—for here was the very particle which his mathematics demanded, one of the same weight as the electron but of opposite charge. In place of two kinds of building brick, it now seems that nature makes use of four, the same number curiously enough as the earth, air, fire and water of Greek speculation.

Are there any more kinds of building brick still awaiting discovery, or is all the matter that we know built up of these four units? Is each and all of these particles really fundamental, or can any of them be regarded as being itself built up from two or more of the others? These are the sort of questions which have been raised, and must sooner or later be answered, as a result of the successive discoveries of Chadwick, Anderson and Blackett. They are questions which may at first sight seem of academic interest only. But on the answers which we give to them must depend our ideas of the whole pattern of material things as well as of the aesthetic rightness of nature's arrangements. If there are both positive and negative electrons, why should there not be negative as well as positive protons. Is nature, in fact, symmetrical or lop-sided?

A priori we have, of course, no more reason to expect that nature should build up its atoms one way rather than another. But most of us, whether as scientist or mystic, agree in a general desire to believe that nature is beautifully as well as wonderfully made. So far as this belief is an *a priori* belief it is based on the same tendency that impels any primitive people to create gods in their own image. We recognise that we, if we were set to work to design a new world, would design it as neatly and simply as we could, and for want of any other criterion we jump to the conclusion that the world as we know it is designed on similar principles. In justification it can only be said that the whole tendency of scientific research has been, not merely to unify for the sake of convenience, but to discover what appear to be real unifications beneath apparently disconnected phenomena.

At first sight, for example, there would seem to be little in common between sunlight, X-rays and the waves of wireless. Yet we now know that all these are different kinds of "wave", that they all travel at the same speed, and that they are all, in the last analysis, produced in the same way. Nature has in fact used the same mechanism to produce each of these kinds of wave, as well as the infra-red waves of fog-piercing photography and the ultra-violet waves used in medical treatment. The normal sequence of discovery is—simplification, new complication, still greater simplicity. It is natural therefore to suspect that, when any one of the pictures provided by science becomes too complicated, it is not final.

Our knowledge of nature's building bricks is under-

going such a weeding-out process at the present time. The discovery of the neutron caused just as much disturbance in scientific theory as the original discovery of the electron. No longer could all matter be built up of two units. Then came the positron, and the bounds of speculation were enlarged. Hitherto cautious scientists began to wonder whether the nucleus of the helium atom, which weighs four times as much as the proton and neutron, might not also be one of nature's fundamental units. Helium nuclei, also known as alpha particles, are one product of the natural breakdown of radium. They are also a common product of artificial atom-splitting. Might they not be more than an unusually stable grouping of protons and electrons?

Then America provided yet a fourth addition to the list of possible building bricks. This was the "deuton", the nucleus of heavy hydrogen, which in the shape of heavy or poisonous water has received a great deal of popular attention lately. Its discovery was mainly due to Professor H. C. Urey of Columbia University, and for quite other reasons is already proving of very great importance. We are not, however, here concerned with the lethal effect of heavy water on tadpoles, or with the fact that it is already helping biologists to solve many hitherto baffling problems connected with animal life. It is more nearly relevant that the deutons of heavy hydrogen have provided atom-splitters with a new form of projectile, with the aid of which many different atoms have already been split in new ways. This is in itself useful because the more strenuously the atom is knocked about

the more scientists can learn about how it is made. But what chiefly matters for atomic theory is the prosaic fact that the nucleus of heavy hydrogen is twice as heavy as that of ordinary hydrogen, the proton, although it carries the same electric charge.[1] Is this too one of nature's building bricks?

Are any of these heavier particles to be regarded as genuine building bricks? Or are they themselves built up of some of the lighter particles already mentioned? No one, naturally, wants to make the picture more complicated than is necessary; and, although there are other reasons for rejecting the claims of any one of them, a single general argument, due primarily to Sir Arthur Eddington, may perhaps be invoked. One of Sir Arthur's hobbies is the linking up of apparently disconnected physical constants—such as, for example, the speed of light, the charge of the electron and proton, and the rate of expansion of the universe. It is a curious pastime, savouring not a little to the layman of magic. But it has led to many suggestive conclusions. In particular, Dr R. Furth of Prague, in a calculation based on Sir Arthur's work and since adopted by him, has been able to demonstrate mathematically that the mass of the proton should be 1838·2 times as great as the mass of the electron. This calculation agrees almost exactly with the best determination of their two masses. The mathematics of this computation may be obscure, and its meaning only imperfectly

[1] There may also be mentioned yet another particle called the "neutrino," most simply described as a double-weight neutron, i.e. it is the same weight as the deuton but carries no electric charge. That, it may be a relief to know, represents the peak of possible complexity.

understood. So much is generally admitted. But so far as this line of reasoning has been carried, it certainly provides an extraordinarily tempting argument for accepting as fundamental only those kinds of particle which have the same mass as either the proton or electron.

The result, if Sir Arthur's views are accepted, is to eliminate at one blow the three heavier kinds of particle already mentioned (the alpha particle, deuton and neutrino); and to leave a "short list" of four possible building bricks—the electron, positron, proton and neutron. It may make for clearness if we now set these four units down in order, together with their weights and electrical charges. In this table the proton is taken as the standard, that is to say its weight is given as 1, and its charge as +1, all other charges and weights being expressed in the same units.

	Weight	Charge
Electron	1/1838	−1
Positron	1/1838	+1
Proton	1	+1
Neutron	1	0

The claims of the electron and positron to be considered as elementary particles are disputed by no one, although four years ago the positron was unheard of. Being of the same weight and opposite electrical charge, they clearly cannot be made of each other, and there is no reason to suppose that any lighter kind of particle exists of which either could be made. In any case their joint existence follows directly, as already described, from Professor Dirac's theory.

On the other hand, the position of either the old

familiar proton, or the newly discovered neutron, is very much less secure. One of these, it is true, must certainly be regarded as fundamental, otherwise it would be difficult to account for their large mass. It could only be supposed that they were each built up of an enormous number of electrons and positrons, which is not theoretically permissible. But, given either the proton or the neutron, the other can be explained in terms of it. Thus the proton might be a neutron (with no electrical charge) in close combination with a positron (unit positive charge). Or the neutron might be a proton (unit positive charge) in close combination with an electron (unit negative charge). In other words one of our four particles can be eliminated, but we are not yet sure which.

That is one aspect of the problem which still awaits solution.[1] Another is the nature of the relationship between weight and electricity. One of the great virtues of the former picture was that these qualities were always found in association. It seemed that there could not be weight without electricity, nor electricity without weight. It could therefore be supposed that, in the last analysis, they represented a single source of energy. That idea seems no longer tenable. If we regard the neutron as fundamental, then we have to explain the existence of a particle which has one quality but not the other. If, instead, we choose the proton, then we have to explain why it and the positron should have different

[1] From the point of view of the mathematician it appears to make no difference whether we regard protons as containing neutrons or *vice versa*. But it may be doubted whether such a solution has any meaning outside mathematics.

weights but identically the same electric charge. In either case the possible unity has been destroyed and, instead of one "unknowable" at the base of the material world, there must apparently be two.

There remains, finally, the question of whether there may not be still another kind of building brick awaiting discovery. As positive and negative electrons are naturally paired, why should there not be a negative as well as a positive proton? It is an attractive possibility, for it would make nature's array of building bricks completely symmetrical. It can only be said that, although scientists have sought diligently for such a particle, they have so far failed to find it. That, it is true, may have no great significance, for the same comment might have been made only a few years ago about the positron—and yet it was there the whole time, awaiting discovery. To prophesy would, in any case, be rash. If such particles really exist it appears, on theoretical grounds, that their relationship to ordinary protons must be of a different kind from that between positive and negative electrons. Dr Dirac's theory, which could properly have been used to prophesy the discovery of the positron, sheds no light at all on the possible existence of the negative proton. The question is therefore an entirely open one—with perhaps a slight bias in favour of symmetry.

How does this modern picture compare with the Greek view of more than two thousand years ago from which we started? At first sight there might seem to be little change. Earth, air, fire and water—to be set against three or four different kinds of not very romantically

named particle. Yet the modern view of the atom has already led, as we shall see in the next "unsolved problem", to a changed outlook on much that was before taken as certain. And, whereas our knowledge is practical, Greek "knowledge" (the criticism is not intended to be general) was solely founded on speculation.

"Practical"? After an unavoidably abstract survey of protons and electrons, neutrons and positrons, a slight lift of the eyebrows is perhaps excusable. We may remember however that the whole of modern chemistry, with its dye-stuffs and synthetic drugs, its new knowledge of the human body, its artificial silks and its artificial resins, is nothing more or less than the direct result of the cruder atomic theory of the nineteenth century. Such a mass of useful knowledge could never have been reached empirically. It could only have been won, as in fact it was won, with the guidance of a coherent theory. The physics of the atom itself may well prove of equal importance. The moral is less immediately striking because the new knowledge has had less time to mature. Yet there are already indications that the exploration of the atom may bring other rewards than the satisfaction of intellectual curiosity.

To the electron, derived from the outer part of the atom, we already owe the radio valve, as well as the advent of practical television; and man's strange habit of atom-splitting has lately shown that perfectly normal materials, for example an elephant's tusk, can be artificially rendered radio-active. It may be that medicine has here a cheaper and more convenient substitute for radium. It may be also that the new radiation, from the new radio-

active materials, may prove superior, for some purposes, to the old. The hospital experiments which will answer these questions have barely been begun. Although science has abandoned the idea of obtaining cheap energy for industry from the atom, it is by no means willing to admit that its new knowledge of the atom is likely, in the long run, to be useless.

CHAPTER XII

MATHEMATICS OR COMMON SENSE?

"A MAD world", so Shakespeare once said. At times, lately, many of us must have been tempted to believe him right. We have seen English fishermen throwing herring back into the sea, American farmers slaughtering pigs by the thousand, and Brazil wantonly destroying its once lucrative coffee. We have heard the nations talking of peace and watched them preparing for war, and we have known that "this also is vanity". But, however crazy human behaviour may seem, we like to imagine that nature at least is well ordered. In the preceding chapter we have seen that the whole world is sensibly constructed of quite a limited number of building bricks. Can we also count on it to behave sensibly?

Can we be sure that St Paul's Cathedral in London or the Empire State building in New York will not jump suddenly into the air? Can we be confident that an iron placed on a cold table will not get hot of its own accord? Is there any such thing as cause and effect? A generation ago such questions, at least the last of them, would have smacked of madness. To-day, the reality of the reign of cause and effect in nature, which means in everything we know, has become one of the great unsolved problems of science. It is perhaps the profoundest of all the

problems with which modern science is faced. The mechanistic world picture has broken down, and, although a new picture has been provided, no one is yet sure what its meaning may be.

During the greater part of the last century very few scientists, or for that matter philosophers, had any doubt about the main question. The future of the world was regarded as essentially calculable from its past, the position being most logically expressed by Laplace—that same scientist-mathematician-philosopher who told Napoleon that he had no need of the hypothesis of a Creator. Laplace, it is true, did go so far as to invent a hypothetical "world spirit". But he was careful to make it clear that his world spirit was hypothetical, and that the only reason he invented him was to provide a good illustration of his materialistic beliefs. It remains to-day the most perfect statement of the problem.

What Laplace said was, in effect, this. Let the world spirit have both perfect knowledge of scientific law and of everything in the universe at any instant; then the world spirit will be able, by taking sufficient thought, to calculate the future condition of the universe at any subsequent period. He will know of the coming of hurricanes and earthquakes a hundred years hence, where each atom of the sea will be in a million years' time, and even, so Laplace thought, the whole future of the human race. That picture was widely accepted. So far as the physical world was concerned, it was unquestioned. And Darwin's theory of evolution, backed up by the discoveries of biologists, was largely responsible for its

acceptance in the case of living beings also. To-day we are not so sure—even about the physical world.

The first rift in the strictly commonsense view of the universe may be traced to what is known as the "kinetic theory" of gases. This theory, which is not nearly so formidable as its name, was developed about the middle of last century and, in the field of experiment, has been brilliantly successful. It will explain quantitatively, for example, how the pressure or volume of a gas changes with temperature, and why different gases pass through a porous material, such as a clay pipe, at different speeds. Its essence is that all the particles of a gas are supposed to be in state of perpetual movement, and that their combined energy of movement represents the heat energy of the gas. Heat, in fact, is movement, the same principle being later extended to both liquids and solids, although their particles have not the same freedom of movement as those of a gas.

There is nothing in this theory which, by itself, is in any way destructive of cause and effect. Its significance is rather different. It drew direct attention to the fact that many of the so-called "laws" of science are dependent for their fulfilment on the co-operation of millions of millions of individual atoms, of whose behaviour as individuals no account whatever is taken. The responsibility for the maintenance of law and order in the physical world is transferred to the atom—a somewhat ominous change-over when it is remembered how relatively little we know about atoms, and how many of them there are to keep an eye on.

In working out the kinetic theory of gases, for example, scientists neither know nor want to know the way in which individual particles are behaving. They merely assume that, just as a penny tossed a million times will come down roughly half a million times "heads" and half a million times "tails", so the millions of millions of gas particles can be counted on to obey the laws of probability. That is to say that, if a million gas particles are moving in a particular direction at a particular speed, it can be safely assumed that a roughly equal number of particles will be similarly moving in the opposite direction, and so on.

It follows that all the conclusions drawn from the kinetic theory are not laws but statements of probability. We know that if we toss a coin twice, the odds are three to one against it coming down heads both times; seven to one, if we toss it three times; fifteen to one, if four times; until, if we toss it a million times, the odds against it being always heads become almost inconceivably great. But we can never be quite certain this will not happen. As any gambler knows, no run of bad luck is so long that it cannot go on longer.

As soon as this idea is applied to the kinetic theory, extraordinary conclusions begin to follow. They are most obvious in the case of solid bodies which, like gases, are to be pictured as made up of a large number of particles moving incessantly to and fro. The pressure of St Paul's Cathedral or the Empire State building on its foundations is due, in the last analysis, to the downward battering of these particles. It only remains constant because there

are so many particles in the bottom layer of each building that as near as may be the same number must be hitting the foundations the whole time. But there is no logical reason to suppose that they will go on doing so. It is perfectly possible that all the atoms which make up St Paul's or the Empire State building might one day take it into their heads to move upwards together. Either building would, then, momentarily leave the ground. They might even continue to move upwards for an appreciable time, so that the whole building would jump an inch, or a foot, or ten feet into the air, according to the degree of improbability allowed.

However improbable such events might be, they could never become impossibilities—just as, however many times we tossed our coin, we could never be absolutely certain that it would not come down heads every time. Admittedly it would be a good gamble to suggest that this is not likely to happen. The earth is supposed to be somewhere about three thousand million years old. In round figures, a bricklayer would have to wait until the earth was roughly three hundred million times as old as it now is before he would be likely to find a particular brick jumping high enough from the ground to come to rest in his hand, working on the third storey of a building. The probability of a complete building behaving likewise would, of course, be incalculably smaller. But however small it might be, it would still be there.

Finally, as this sort of calculation has at least an element of the fantastic, we may turn from mathematics to reality and, looking through a microscope, watch for a moment

the behaviour of some minute solid particles which happen to be floating about in a tumbler of water. They are so small that we can only see them through a powerful microscope. They are also in violent movement, darting about hither and thither without, apparently, any rhyme or reason. We cannot see why they are being knocked about. But then we cannot see the even smaller molecules of water which are rushing about still more violently. That, of course, is the explanation. The solid particles are so small that they cannot count on the laws of probability being observed in their case. At one moment they may receive more knocks on one side than on the other. They therefore move rapidly away, as we should ourselves in similar circumstances, from the direction from which most knocks are coming. In fact, they are behaving in very much the same way as St Paul's or the Empire State building might behave—but on a very much smaller scale.

It was only gradually realised that most, if not all, of the "laws" of science had a similar statistical basis. Any natural process is dependent on atoms, or on the still smaller particles of which atoms are made. The conduction of heat or electricity, every chemical change, the power of a magnet to pick up steel pins—each is dependent on the co-operation of countless legions of individual atoms and electrons. Each atom may go its own wilful way, but, provided that there are enough of them, their combined behaviour will be, for all practical purposes, predictable. Yet, like the stability of St Paul's, it will be no more than a probability.

Not yet, however, had Laplace's world spirit cause for anxiety. It is not for us to number the atoms, and reckon up the behaviour of each one separately. But Laplace's world spirit was endowed with infinite patience and skill. He, it might be supposed, would be capable of observing the state of each atom, each electron in the universe—and then, by the application of scientific laws, he would be able to predict what they would all be doing an hour, a day, or a million years hence. If St Paul's were ever going to forsake the ground, or your family iron to draw heat from a cold table, he would be in no way surprised. He would have been able to calculate in advance the precise instant at which these most strange things would happen. Always supposing that the individual atom and the individual electron is amenable to scientific law, in the strictly causative sense.

This is the crux of the matter. Can the individual atom be counted on to behave sensibly? We meet our first serious doubts at the beginning of the present century, with the discovery of radium. Here we have a chemical element with the strange property that in every thousandth of a second a certain proportion of its atoms will break down of their own accord into atoms of a different kind. So far as we know, it is purely a matter of individual idiosyncrasy. We cannot attach labels, marked "Beware. Explosion imminent", to particular atoms. To all appearances they are all alike. Nothing that we can do can alter the rate at which these "explosions" will take place. All that we can say is that out of every million radium atoms, one will be taken and the other 999,999 will be

left. But we cannot tell which the one atom is going to be.

To-day the same difficulty is both more general and more acute. It has become obvious that radium atoms are by no means the only offenders. The real trouble is that the behaviour of every electron in the universe seems to be individually unpredictable. In fact it is now recognised that we cannot even be sure what any individual electron is doing at the moment. There is an important distinction here from the position in the case of gas molecules. With these we had simply no need to bother about what individual molecules were doing. In the case of electrons it seems that we cannot know. The problem that still remains to be solved is whether their apparent irregularities are real—or merely the result of ignorance which may later be removed. It is a problem which involves nothing less than the whole reign of cause and effect in the physical world. Are happenings in the physical world determined by what has gone before? Or should precise scientific laws give place entirely to probabilities? Putting the same question in another form, are "miracles" possible?

Perhaps because English-speaking peoples naturally prefer commonsense explanations, the revelation of this apparent uncertainty in nature has been mainly the work of continental scientists. The trouble began when the German scientist, Max Planck, produced his famous "quantum theory"—which in the beginning was a set of rules rather than a theory in the ordinary sense of the word. As it leads to even more extraordinary conclusions

than does the kinetic theory of gases, it may be well to emphasise that it was in origin very far from speculative. It was designed to explain the observed facts about the radiation of light and heat from a solid body—for example a red-hot poker or an electric lamp filament. There could be nothing, one would have thought, more prosaic or farther removed from the largely philosophical problem of cause and effect.

Planck's great discovery was that wave energy, like matter, was atomic. Nature will (so to speak) produce an "ounce" of light, or heat waves or X-rays—or two ounces or three ounces, but nothing in between. In other words a definite packet of energy must be available if any radiation is to be produced at all, although it turned out that the size of the standard packets varied with the type of radiation. Standard packets of deep red are, for example, just about half as big as the standard packets of the extreme of violet which the eye can see. In general, the packets get bigger as the wave-length is reduced, so that for the production of the most penetrating X-rays, which have a very short wave-length, a very considerable amount of electrical energy is necessary.

The size of the energy packets is not therefore fundamental. It is, however, possible to define an entity known as "action", the standard packets of which are the same for all kinds of radiation. This term had already a perfectly definite meaning in mechanics. But it will probably be sufficient to remember that the atoms which Planck discovered were atoms of "action"; and that their existence means, in plain language, that things can only

happen in jumps. Probably there is nothing in the whole of modern science which is more difficult to accept than this idea of jerkiness in nature. Yet if we are ready to believe that matter, which seems so solid and sensible, is really discontinuous, why not energy and "action" too?

Planck's quantum rules were, however, in the first instance only designed to account for the facts of heat radiation, and although they did so perfectly they were received with a good deal of quite natural suspicion. It was at this point, when most scientists were frankly unbelieving, that Einstein decided to take a hand. He found that a similar set of rules could be applied to the photo-electric effect, the shooting out of electrons from matter by light, which is now the basis of television. Here also Einstein found that Planck's mysterious energy packets were necessary if the observed facts were to be explained.

Finally, emboldened by this success, the Danish scientist, Niels Bohr proceeded to adapt the new rules to the atom itself. The atom, it will be remembered, consists of a heavy nucleus round which revolve a number of outer or planetary electrons. The antics of the latter had been already connected with the radiation of light of particular wave-lengths by gases when they were heated. But there was one very serious difficulty. Thus it was natural to suppose that the wave-length of the light radiated by an electron depended on the time it took to revolve round the nucleus. This in turn would depend, in accordance with the ordinary laws of mechanics, on the orbit in which it moved. The difficulty was that there was no valid reason for restricting the electrons of any

atom to particular orbits. Every atom should therefore be capable of radiating any wave-length—which the veriest schoolboy could show was not the case.

Realising the inadequacy of the existing picture of the atom, Bohr decided, just as Planck had done before him, to take a leap in the dark. Without further apology he laid down his own rules for the behaviour of planetary electrons. He said: (1) that no electron radiated any light at all so long as it continued to revolve round the nucleus in its original orbit, (2) that the electrons had only the choice of a limited number of orbits, corresponding with 1, 2, 3 and so on of Planck's packets of "action", and (3) that light was only radiated when an electron jumped from an orbit of higher energy to one of lower energy.

All this was exceedingly high-handed, not to say irregular. Bohr knew perfectly well that, according to the accepted laws of mechanics, an electron ought to be able to occupy any orbit it liked; and that, according to the accepted laws of electricity, an electron should continuously radiate energy the whole time that it revolved in a closed orbit. Yet he preferred to ignore both and to substitute his own purely arbitrary rules.

. It proved a clear case of insubordination being profitable. The new rules worked amazingly well. With their aid Bohr was at once able to calculate the precise wave-lengths of light which should be radiated by the simplest kind of atom, those of hydrogen; and it turned out that the calculated wave-lengths corresponded with the observed wave-lengths with far greater accuracy than could

possibly be ascribed to chance. Here, then, was a theory, highly successful, but consisting of nothing more than a series of purely arbitrary rules for the designing of atoms. They seemed to be correct, but no one could say why. Moreover, the seeds of uncertainty had been already introduced. No hint was provided which might help to explain why, at any particular instant, one electron rather than another should choose to execute one of these radiation-producing jumps.

Two things, at any rate, are certain. The quantum theory, or some modification of it, is essential if the behaviour of atoms is to be accurately pictured; and the quantum theory in the form in which it has so far been described could never have been accepted as final. However great its practical successes, it was merely a series of *ad hoc* rules, at the same time inconsistent with hitherto accepted theory and devoid of any logical foundation. Two examples of the first type of difficulty have already been mentioned. Bohr's electrons, according to all accepted theory, should have been able to occupy any orbit and should have radiated continuously. The inconsistency was merely stated. It was never explained. An example of the second type of difficulty is the impossibility of imagining how and why an electron should instantaneously jump from one stable orbit into another, somehow managing to alight precisely and exactly in its new path.

In each case the difficulty is at bottom the same. Particles simply do not behave like this. The time-honoured conception of the particle is therefore an

inadequate foundation for any theory which seeks to explain happenings in the atomic world. Bohr's theory of the atom broke down for precisely the reason that it is most attractive. It was the last theory of the atom which could be represented by a material model.

It was inevitable therefore that mathematicians should endeavour to provide a coherent picture which should include just as much knowledge of the electron as could be experimentally obtained—and no more. This has been done by ceasing to regard the electron as a particle in the ordinary sense, and by putting in its place something which is mathematically described as a wave system. At first sight the way of escape may appear even more difficult than the difficulties it was designed to avoid. Yet Planck had already found that light, which was normally regarded as consisting of waves, must from some points of view be regarded as being built up of particles. It was therefore natural to try the effects of making the opposite conversion in the case of matter.

What the mathematicians said was this. By all means keep your familiar ideas of particles for some purposes. But let us, for other purposes, replace your particles by a series of wave equations, and see what happens. The experiment, crazy though it may sound, proved a success. It was soon found by Davisson in America that electrons really did behave as waves under some conditions, and could be photographed doing so. In the second place it turned out that the wave equations for an electron made provision for the existence of a centre of energy, corresponding with the former concept of a particle. Even

more important, the new wave picture of the electron was self-consistent, would explain everything which Bohr's rules would explain, and a good deal more as well.

It will explain, for example, the power of metals to conduct electricity and the main facts of radio-activity. In addition, it could have been used, as mentioned in the preceding chapter, to predict the existence of the then undiscovered positive electron. These are important achievements. In greater detail, this most abstruse and mathematical of modern theories will also explain why one particular kind of brass, out of all the range of brasses, has the colour of silver; and why the electrical resistance of another alloy, known as constantin, varies hardly at all with temperature, an unusual property which renders it of considerable value to the electrical industry. These latter, admittedly, are relatively minor achievements. Yet they are impressive, if only as showing that the quantum theory can be successfully brought down to earth.

For the working scientist the wave picture is therefore preferable, provided that there is a mathematician at hand to steer him safely through the necessary calculation. Quite a small proportion of scientists, even of those dealing with the atom, are capable of doing it for themselves. It is an extraordinary, almost a dangerous, position. But for the man in the street, the chief interest is in the connection between the two pictures. The wave picture, it seems, represents the probability that what we call a particle will be in a particular place, and moving

at a particular speed, at a particular time. Uncertainty about the behaviour of electrons has been transferred from observation to theory. That is the real significance of the modern quantum theory.

The present position is therefore that the wave picture is universally accepted by scientists as at least a working hypothesis. They are concerned with its practical implications, not its philosophy. And, from the point of view of results, there is no doubt about its excellence. But when it comes to the final significance of the wave picture opinions differ. It may be that the equations of "wave mechanics" go as near to providing a final picture of the electron as we are ever likely to get. In that case the conclusion is inescapable that there is no such thing as cause and effect. Everything is merely a matter of probability, and not even the Creator could predict the future course of the universe with certainty. He could only know that the universe which he created had borne the seeds of uncertainty within itself from the beginning. If this is true, it is a conception of which philosophy, and probably religion also, will have to take account.

Equally, however, we are entitled to believe that this uncertainty is merely temporary. It is possible to accept the wave picture as a working hypothesis, and yet to believe that it is one day destined to be superseded. In a fuller picture the reign of cause and effect may be restored. Some words of St Paul are unexpectedly appropriate: "We know in part, and we prophesy in part." We can know a little about where an electron is and how it is moving, but we can never know

all about an electron. So also we can only prophesy in terms of probabilities. "But, when that which is perfect is come, that which is in part shall be done away." Not even a Fundamentalist would claim that St Paul should be regarded as an authority on atomic theory. Yet it so happens that Planck, who originated the quantum theory, agrees with him; and so does Einstein, who did so much to develop it. Both believe that the reign of cause and effect may well return, and their opinion is obviously entitled to respect. On the other hand both Sir James Jeans and Sir Arthur Eddington regard the uncertainty as an uncertainty of nature. It is as if the four of them had agreed to stage an international doubles contest—Germany *v.* England. At present there is nothing to be done but to await the issue. If anything, the odds are slightly on England and away from common sense. In the meantime the plain man can take his choice. Whichever side he elects to back he will have authority behind him.

CHAPTER XIII

THE SECRET OF STRENGTH

A STEEL girder should be a hundred or a thousand times as strong as it is. Bridges should be built many times more cheaply. Aeroplanes should be immensely lighter than now appears possible. In each case, the atoms of which they are made flatter only to deceive. It is known, in the main, how different materials are built up. It is known also what should be the forces which bind the different atoms of the network together. Yet, when the calculation has been made, it is proved by practical experience to be grotesquely optimistic. It is no use telling an engineer that a girder should support a weight of a thousand tons, if he knows from his book of tables that it can only be relied upon to support between one and ten. That is, from one point of view, the problem of the solid state. No material is as strong as it should be. To enquire why, is, to the scientist, a matter of natural curiosity. But it by no means follows that the enquiry will remain merely academic. If the cause of the weakness is ever certainly established, it may also prove possible to raise the practical standard of strength.

In some ways a crowd of atoms is not unlike a crowd of human beings. A crowd may do things which none of its members as individuals would dream of doing. So also, atoms in the mass take on different properties from

atoms as individuals. Just as mass psychology is the study of the behaviour of crowds as a whole, so X-ray analysis presents a picture of the ordered arrangement of atoms in nearly all solid materials, and enables its consequences to be deduced. But in neither case can the individual be left wholly out of account. There must always be one man who is prepared to shout "Crucify Him". In Paris, more than seventeen hundred years later, one man must first have raised the cry, "To Versailles". When the retreat of an army is turned to rout one man must be the first to break. So, probably, is it with the breaking of solid materials, whether it be the snapping of an engine's crankshaft, running at speed, or the collapse of a railway bridge during a storm. X-rays provide an ordered picture of the atom ranks. But it is to-day recognised that, even when dealing with atoms, the personal factor cannot be left out.

More than twenty years ago Dr Laue in Germany discovered that X-rays could be used to indicate the distances which separated successive layers of atom in a crystal. Here, it seemed, was the clue to all the physical properties of every kind of crystal. Only let the lay-out of the atoms be exactly known, it was hoped, and the reason behind every type of property which the crystal might possess would stand revealed. The goal was not indeed so explicitly stated. But as knowledge of individual atoms accumulated, and the technique of X-ray analysis was gradually perfected, largely through the work of Sir William Bragg and of his son Professor W. L. Bragg of Manchester, the hope appeared to be not unreasonable.

To-day the very accuracy of the X-ray method emphasises the inadequacy of the picture it provides. This is not to suggest that X-ray analysis has been a failure. On the contrary, it has proved invaluable to the metallurgist, providing him with a wealth of information about the alloys with which he deals. To the biologist it has demonstrated that ordered architecture is much more nearly universal in nature than had been before realised. Such apparently non-crystalline materials as woods and vegetable fibres, nerve and muscle, hair and wool, have been shown to possess an ordered structure. X-ray analysis has even helped to throw some light on the cause of the well-marked difference between the hair of negroes and that of whites. To the organic chemist it has given pictures of almost photographic accuracy of many of the complex molecules with which he deals. No matter how complicated the internal structure of a crystal, it has always proved possible, by taking a sufficient number of X-ray photographs, to work out the whole elaborate network. Yet the disappointment has been undeniable. On the one hand there is precise agreement in atomic measurements as between different specimens; on the other, a lamentable variety in the behaviour of the crystals in question under practical conditions.

Rock-salt has, for example, a simple cubic structure. Measurements of the length of the elementary cubes of which it is built up, made by different workers on different specimens, agree to within less than one part in a thousand. If this does not sound impressive, it may be added that the distances in question are of the order of a thousand-

millionth of an inch. Modern X-ray workers are therefore measuring the position of atoms to within a million-millionth of an inch, roughly ten million times smaller than the smallest distance which can be seen in the most powerful microscope. Yet, in spite of the accuracy of the measurements, what do they find? Many of the most important properties of the materials examined vary from crystal to crystal, although X-ray analysis provides no clue to any difference. Strength varies, power to conduct heat and electricity varies to a lesser extent, and so do the colour changes produced in the crystal by radiation. Clearly some other factor is involved, besides the ordered arrangement indicated by X-rays. Moreover the "other factor" is very far from being negligible, as is shown by the enormous discrepancies between the calculated and actual strengths of materials.

In one sense, the cause of the trouble lies very deep. Science has not, so far, found it easy to handle atom crowds. Of the three possible states of matter, most is known about gases. Such varied properties as, for example, the rate at which a gas will force its way through a porous material and the speed at which it will transmit sound can be calculated on purely theoretical grounds with very fair success. This is because the different particles of a gas are, relatively speaking, distant neighbours. Their mutual interactions can for most purposes be ignored, or at the most only taken into account as an extra refinement. Each particle can in fact be treated as a separate entity, and the properties of the gas as a whole worked out by purely statistical means. Both in liquids

and solids matters are very much more complicated. Water, for example, is seventeen hundred times more dense than steam, and in all liquids the forces between different particles are of dominant importance even if each particle still retains its freedom of movement.

In solids, on the other hand, each atom is bound by its neighbours. It is true that they must all be pictured as in a continual state of movement. But this movement is no more than a relatively small vibration about the central position of each atom. If it gets too big, so that the mutual forces between the atoms are no longer sufficient to hold them in place, then the solid ceases to be a solid and melts. That is the real difference between a solid and a liquid. A liquid is like a crowd, temporarily confined by a police cordon within the limits of some square, but within those limits free to move around as it wills. A solid is like an army which, by some unusual extension of the "stand easy" order, is allowed freedom of movement within the ranks, so long as no man encroaches too closely on his neighbour's position. He may take one pace forwards, or one pace backwards—in fact is continually doing so—but no more. This means, mathematically, that the properties of a solid can no longer be averaged out from the behaviour of the individual atoms as a whole. Each atom is bound by its neighbours, and so their arrangement, as well as their numbers and speed of movement, become important.

This requirement is both the strength and the weakness of the X-ray method. X-ray analysis provided for the first time a tool by which the ordered array of atoms in a

solid could be explored. To a much more limited extent the method is also applicable to liquids, although even a roughly ordered array is in their case exceptional. In any case the method is essentially one which deals with atoms in the mass. The way in which X-rays are scattered at a crystal surface provides conclusive evidence that the atoms are, in general, arranged in rows of such-and-such thickness, with each atom in the row so far apart from its neighbours, and so on. The measurements are exact, and the crystal lattice is exact, but X-rays provide no evidence that it is universal. If one row of atoms was missing or distorted there would be no sign in the X-ray photograph. A minute flaw might run the whole thickness of the crystal and still be invisible. The lattice, as shown by X-rays, must be the primary structure of the crystal, but there might, for all that X-rays might show, be a secondary structure superimposed upon it. In every, say, hundred atoms, there might be some regular departure from the straightforward array. All or any of these factors might alter the strength of a crystal, or indeed many other of its properties, and so long as we were dependent for our knowledge on X-rays we should know nothing about it.

That is the sense in which X-rays have been a disappointment. It was at first supposed that the ideal structure could be taken as corresponding, in the main, with the real. Practical discrepancies suggest that this is one of those cases in which the exceptions are at least as important as the rule. The discrepancies, moreover, do not merely depend on theoretical calculations of the binding forces

between different atoms. Crystals which may appear identical, and which give identical X-ray patterns, may yet have different strengths and different powers of conducting heat and electricity. Reluctantly, it has to be admitted that X-rays do not tell the whole story.

Attention was directed to the problem as early as 1920 by Dr A. A. Griffith, of the Royal Air Force establishment at Farnborough, who showed that, under special conditions, freshly drawn glass or silica fibres could be prepared which were fifty times stronger than usual. It turned out that the fibres which he prepared were unstable, reverting to their normal weakness soon after being first drawn out. However, the main interest of Griffith's discovery to-day is that he was led by it to put forward the first of many theories intended to explain the normal weakness of the material with which he was dealing. From the way in which the breaking stress of these fibres varied according to their thickness, he at first supposed that they had a strong surface layer and a relatively weak inside. He suggested also that the internal weakness was due to a large number of sub-microscopic flaws. To explain the strength of the surface, he had to suppose that the internal flaws ran parallel to it. To-day the idea of sub-microscopic flaws is still fashionable. But both common sense and the evidence of experiment suggest that such flaws would be most likely to be dangerous when they reach the surface.

Right or wrong, Dr Griffith's theory was the starting-point of a number of extraordinarily ingenious experiments. Their general object has been to test the relative strength or weakness of the surface layer, or to show by

indirect means the real existence of the supposed cracks. Theoreticians have been equally busy constructing mathematical equations to explain the observed results. Not less than half a dozen countries have made significant contributions, in one way or the other, and there are certainly few problems which to-day excite more interest among physical scientists.

It was Professor A. Joffe of the Physico-Technical Institute of Leningrad who really set the ball rolling. By etching away the surface of a glass rod, and measuring the strength of the rod during the process, he launched a direct and probably unanswerable attack on Dr Griffith's theory of surface strength. After the removal of its original surface the rod had a strength which, in proportion to its thickness, was from three to five times as great as that of the original rod. In addition, the strength after etching corresponded well with that of fibres drawn from a flame and immediately examined, the very method by which Dr Griffith had obtained abnormal strength. From this experiment alone, it would be legitimate to conclude that the trouble was in the surface, and that Dr Griffith's original success was due to the fact that the surface weakness which normally occurs had not been given the opportunity to develop. It has also been shown that the strength of both glass and quartz fibres is weakened by the adsorption (surface absorption) of both water and alcohol vapour. These experiments also suggest strongly that the change is in the surface.

Another experiment, also performed by Professor Joffe, points to the same conclusion. If the normal strength of

rock salt is represented by 0·4,[1] he found that values up to 160 could be obtained by making his measurements with the crystal immersed in hot water. Here again the effect of the experimental conditions is to remove the surface layer of the crystal. An alternative explanation, put forward by Professor Joffe's critics, has not stood the test of experiment. It seems therefore that, under average conditions, he has achieved a genuine increase in strength of twenty-fold or more in this way, while the extreme value already quoted makes a close approach to the figure of 200 reached by purely theoretical calculation.

Finally, Professor Joffe is also responsible for one other experiment of a quite different type. It is well known that local variations in the expansion of any solid body when it is heated may result in a severe strain on the material. Any housewife, for example, knows that the use of boiling water in "washing up" is apt to lead to disaster. The reason is that the outside of the glass, or whatever it may be, expands as it is heated; while the inside, which for a time remains relatively cool, is unable to keep pace with this rapid expansion of the surface. The glass is, in the language of international politics, in a state of acute tension. Sometimes, particularly if it is already cracked, it will break. In this case the rise in temperature is not very great—at the most, and on a cold day, perhaps 170 degrees. Professor Joffe was very much more drastic.

Instead of starting with his "crockery" at room temperature, he began by cooling them in liquid air to a temperature about 440 degrees lower. Then, instead of

[1] Milligrams weight per square millimetre of cross-section.

boiling water, he plunged them into molten tin. In this way he secured a sudden rise in temperature of more than 800 degrees. It should have been enough, one would have thought, to have satisfied even the most destructive of music-hall scullery-maids. Even under these conditions, his crockery remained intact. This consisted of a number of rock-salt spheres—rock-salt because that was the material he was experimenting on at the time; spheres in order that the degree of strain produced could be simply calculated. It corresponded with a minimum strength of 70 of the same units, compared with rock-salt's theoretical strength of 200 and a maximum practical strength of 160 with the crystal immersed in hot water.

The experiment just described did not, of course, give a measurement of strength. It merely gave the minimum strength which the inside of the crystal must have possessed, or it could not have remained intact. The three figures are therefore perfectly consistent.

Yet another, and perhaps even more convincing, proof that the cause of weakness is in the surface has been provided by Dr E. Orowan of Budapest. Professor Joffe has been associated with four different methods of attack. All his experiments are ingenious, and at least three of them absurdly simple. Yet the simplest of all is Dr Orowan's. All he did was to measure the breaking strength of mica when tension was applied through clamps much narrower than the width of the mica strip, so that the edges of the strip were practically unstressed. In fact he measured, quite directly and straightforwardly, the breaking strength of the middle section of the strip.

Once again it proved that the middle of the mica was relatively strong. He found an eleven-fold increase, while with thinner strips an increase of as much as twenty-fold has been obtained.

To explain these facts Professor Joffe supposes that there are a variety of faults inside the material. When they reach the surface they give a variety of discontinuities with differing influence on the strength. Internal faults do not matter, so long as they do not reach the surface; nor, from the point of view of strength, do any but the biggest faults. A crystal, like a chain, will break at its weakest link. So far the picture is purely general, and unhampered by any awkward implications. Even looking at the problem in this simple and essentially non-mathematical manner it is, however, possible to make one type of prediction. Assuming that the distribution of faults is a purely random one, it is natural to suppose that big faults will be less common than small faults. Professor Joffe therefore supposes that a small specimen will be more likely to be strong, relatively, than a big one. The chance of a "grade one" fault will be less, in exact proportion as the surface area of the specimen is smaller. Professor Joffe has looked for this effect, and found some evidence that it is real. Testing a large number of glass filaments, he found that thinner and shorter filaments tended to be stronger than thicker and longer ones. He also found that variations between individual specimens were greater as their size was reduced. This again was as it should be.

Finally, Professor Andrade of University College, London, has obtained a number of photographs which

seem to indicate some of the lines which these surface cracks follow, although the cracks themselves are much too small to be visible. Professor Andrade has found that when a thin film of gold or silver is "sputtered" on to various surfaces in a vacuum, the minute gold and silver particles tend to collect in straight lines—in other words, along the much-debated invisible cracks. He has certainly a good deal of support for this belief. The lines, for example, are definitely not due to surface impurities. If the surface is cleaned and heated in a vacuum, and then a fresh film deposited, the identical pattern of lines reappears. The appearance of these lines in the case of diamonds is even more striking.

Sir Robert Robertson, the British Government chemist, had discovered a year or two earlier that there are two structurally distinct types of diamond, although the eye can detect no difference and both types sparkle with equal brightness. The more common of these types, known as type one, he had independently deduced must be free from submicroscopic faults. Type two, on the other hand, he had deduced must have a mosaic structure, the latter term being more or less self-explanatory. This discovery has afforded a particularly attractive check on Professor Andrade's belief. By sputtering metal films on both types of diamond, he was able to show that only type two collected his metal particles in lines. In addition the direction of these lines corresponded with the known intersection of different crystal planes within the diamond.

It might seem that these experiments of Professor Joffe

in Leningrad, Dr Orowan in Budapest and Professor Andrade in London had cleared up the most essential part of the problem. In a sense this is true, but as so often, when one of the pictures presented by science is not yet complete, the apparent simplicity has only been achieved by ignoring, for the moment, whatever is not convenient.

One complication is represented by the possible existence of a "secondary" or coarser structure within crystals, which having been mentioned at the beginning of the chapter has been allowed to drop quietly out of the picture. The position in this case, although by no means satisfactory, can be quite simply stated. Two scientists in particular, Dr Zwicky of Pasadena and Professor Smekal of Halle in Germany, have devoted a great deal of time and trouble to building up theories which would account for the regular appearance of such wider networks of atoms. On the other hand, a third scientist, the same Dr Orowan whose experimental ingenuity has already been mentioned, has advanced a whole battery of reasons for believing that any such secondary structure is impossible. The present position is not a little ridiculous. Dr Orowan is supported, on theoretical grounds, by Sir William Bragg—but experiment, if anything, points in the opposite direction.

Whatever theory may say, it does look as if the attack of solvents of any kind on crystals does produce definite "etch patterns", and it is most natural to suppose that these patterns correspond with more or less regularly repeated variations in the structure of the crystal. At any rate Professor Goetz of the California

Institute of Technology has found lines of this kind on the surface of bismuth at intervals of about one twenty-thousandth of an inch, and both tin crystals and iron show a similar effect. Small as are these intervals, they are very large compared with the distances separating the individual atoms of the crystal lattice—somewhere about ten thousand times as big. And there, for the moment, the matter rests. Experiment suggests that about every ten thousand atoms, there is some sort of discontinuity or "repeat signal". Theory, or rather theoreticians, say, "Nonsense, it is impossible."

The second complication is concerned with what is known as "crystal slip" which, for practical purposes, is probably even more important than the straightforward breaking of a strictly rigid material. This is the tendency of successive planes of atoms to slip, one upon another, when under strain. There is nothing mysterious about the process in itself. It is very much what happens when a pile of papers, or better still a book, is pressed to one side. Each piece of paper slips a little, with respect to its neighbours above and beneath, so that the complete pile takes up an echelon formation. Any book can be easily enough distorted in this way, although it is presumably not very good for the binding. What is surprising in the case of crystals is that not all the planes slip. It is as if, when the book was pressed sideways, pages 1–50 remained unmoved, pages 51–100 slipped in a solid wedge and so on. Page 51 would have slipped on page 50 and page 101 on page 100, but all the intervening pages would have stayed fixed relative to their neighbours. Yet, so far

as the X-ray picture is concerned, there is no reason to regard any one crystal plane as different from any other.

Even more curious is the fact that the "book", having slipped to a certain extent, is more rigid than before. A single pure crystal of any metal, for example, can be very easily bent, but a somewhat greater amount of force is necessary to straighten it out again. In the same way it has been known for the better part of seven thousand years that copper could be hardened by hammering. Yet science is almost as ignorant of why this process is effective as was its first discoverer.

If, on the other hand, the distorting force is sufficiently strong, one or more of these "planes of slip" will part company with its neighbours, and the book will break in two. This is what happens when a material first stretches and then breaks. It is also what happens when a metal breaks by "fatigue", which is the way in which a large proportion of practically important failures take place, for example, in machinery and under any conditions in which materials are subjected to continually repeated strain. It is as if a metal, like a human being, could stand being maltreated once, twice or even three times; but if the treatment is long enough continued, its power of resistance will be worn down—just as no temper in the world will withstand daily nagging. Presumably these three processes are connected—the tendency of some planes to slip rather than others; the hardening produced by a certain amount of "slip"; and the final complete fracture. But, except that each process is concerned with slipping, it is by no means obvious what the basis of the connection may be.

Professor G. I. Taylor, who has lately been working at the Cavendish Laboratory at Cambridge, has however developed a theory which, for the first time, made a mathematical treatment of the problem possible. In this theory each fault is regarded as arising from the deficiency of a single atom in one row. The resulting dislocation of the normally ordered array is then supposed to be progressively healed in successive rows. This theory yields quantitative results which agree, to some extent, with experimental records both of the spacing out of slip planes and of the hardening effect. But it has only been worked out in the case of cubic crystals and even in their case can only be regarded, for the present, as tentative.

It is curious, this ignorance of solids. The cooling of gases, as they expand, can be calculated and used in the making of liquid air. The pressure of a liquid is evenly distributed, as it should be, in all directions. Electrical engineers can predict within a narrow margin the power which they will be able to extract from their dynamos. Broadcasting authorities can obtain more or less exact estimates of the amount of power which some new station will radiate and of the probable strength of reception at different distances. It is true that when theory is applied to practice, the results are not always exactly as expected. But an explanation is usually forthcoming, and then the revised theory is found to work.

Yet in the ordinary, everyday behaviour of solid materials, theory has proved sadly inadequate. The ordered picture given by X-ray analysis appears to be largely ideal. To-day it is not even certain if there is any

such thing as a really perfect crystal lattice, with every atom in its prescribed position and not one missing. Nor, although we have been talking of flaws as a cause of weakness, is it certain that such a completely perfect crystal would even be particularly strong. In some cases it seems that impurities, once regarded as productive of weakness, may paradoxically increase the strength of the crystal. About the only point which can be taken as at all definitely established is that the normal "weakness" of any rigid material is due to surface imperfections, which are almost certainly cracks. But the cause of the cracks is not known, nor is the mechanism of "slipping", which exacts such a heavy toll in engineering waste, fully understood. Considering that the problem was only recognised a matter of fifteen years ago, progress has perhaps not been too bad. But the physicist has a long way to go yet before he will have satisfied his colleague, the engineer, that he knows what he is talking about. When that happens, the atom will hold a much more honoured position in the practical world than it does to-day.

CHAPTER XIV

NATURE BEATS THE SCIENTIST

IN the chapters which have gone before an attempt has been made to outline some of the main "unsolved problems" which still confront the scientist. Some of them, for example, the creation of the universe, should perhaps rather be classed as insoluble, for however much the field of knowledge may be extended, and however plausible the theories put forward, a large element of the speculative must always remain. In some cases progress may be expected to be rapid, in others it will inevitably be slow. The atom, for example, will probably yield the last of its secrets long before the nature of life has been made clear. Time must also be essential for any full knowledge of either the presumably ordered sequence of the world's weather or of the slow changing of its crust. On the other hand, knowledge of cosmic rays has progressed at a relatively rapid pace, in spite of difficulties in the way of experiment; and within an even shorter time much has already been discovered about the "secret of strength".

Yet, when each problem has been placed in its proper setting, the final impression should be one of change. There can be nothing static about the subject matter of such a book as this. Even as it is being written, and later as the printing press begins to move, new observations

will be in progress the world over which will no doubt in time point the way to solution. New knowledge enables old problems to be viewed in different perspective, so that the very form in which the problems of to-day appear may in the future seem misleading or incomplete. At the same time, new knowledge must again raise new problems for solution, as it has always done in the past. Finality may one day be reached, but for long generations at least it looks as if the quest of science will be unending. The word "quest" is perhaps a good one. It suggests that, however much science may be criticised for changing its mind, everything it does has an ultimate value.

It was not waste that Columbus, discovering America, should have believed that he had found a road to the orient. It has not been waste that Newton should have formulated his laws of motion, nor that the scientists of the last century should have regarded each of the ninety-two kinds of atom with which they dealt as separate and indivisible. The discoveries of Columbus have still their place in the body of modern knowledge, and so have those of the nineteenth-century chemist. Moreover the parallel suggests another resemblance which, as it was emphasised at the beginning, so it may be again be emphasised at the end. Just as the explorers' first knowledge of the American continent had to be incorporated in a wider picture, so the pictures put forward by science are not so much inaccurate as incomplete. The results of experiment remain of value, although the theory which prompted them may be found wanting. Even the theory, at first sight derelict,

will generally be found to have left its mark on the wider, more complete picture which takes its place. It is of the essence of the scientific method that it is cumulative in its effects.

No new discoveries, however widely hailed as revolutionary, can take away the power of the dynamo, the capacity of insulin to prolong life, the ability of stainless steel to resist corrosion, or the broad validity of Mendel's laws of heredity. In the various "unsolved problems", which it has been the main purpose of this book to discuss, attention has been primarily directed to their purely scientific aspect, to their significance from the point of view of knowledge as such. In the long run, however, knowledge implies power, and the progress of science can also be roughly measured by the extent to which nature still beats the scientist, or *vice versa*, in practical achievement. In this remaining chapter attention will be first directed to a number of examples in which science seems to be beating nature; and then to a number of other cases in which nature's skill has so far defied, not only improvement, but imitation. In these also, it need hardly be emphasised, there can be no finality.

It was in 1913 that Mr H. G. Wells, in his book *The World Set Free*, ventured the prophecy that in the year 1933 a scientist would first endow other forms of matter with the power possessed by radium atoms to break down into simpler atoms, in the process throwing out useful radiation. In 1933, the very year which Mr Wells so rashly mentioned, the discovery of artificial radio-activity was made—appropriately enough by Irene Curie, the

daughter of Mme Curie, the discoverer of radium, and her husband, M. Joliot.

Since then progress has been both rapid and spectacular, so that it appears to-day that various substitutes may soon be available for radium, which have not only no counterpart in nature as we know it, but may even be more effective medically than radium itself. The clue has come, as might be expected, from the atom. It may be remembered that its chemical, and indeed most of its physical properties, are determined by its planetary electrons. It is however the nucleus which breaks down in radio-activity, and it is the nucleus also which makes up by far the greater part of the atom's weight. One result of this arrangement which has long been known is that a single chemical element may have atoms of more than one kind. For example, although any tin atom has the same number of planetary electrons, there are no less than eleven different kinds of tin atom, ranging in mass from 115 to 124. Atoms which differ in this way are called "isotopes".

The discovery of artificial radio-activity was simply the discovery that unstable isotopes of known chemical elements could be artificially produced. One of the three first cases examined by Irene Curie and her husband was that of radio-nitrogen. The atoms of ordinary nitrogen have a mass of 14. These two scientists found that by bombarding boron atoms with fast-moving particles from the radio-active element polonium they could produce unstable nitrogen atoms of mass 13. Like the atoms of radium, these radio-nitrogen atoms break down of their

own accord into simpler atoms, and throw out radiation as they do so.

The difference is simply that, whereas all atoms of radium are naturally unstable, other chemical elements may have unstable isotopes which can only be prepared by artificial means. Moreover it is not a question of making ordinary, stable atoms radio-active, but of turning them into different, unstable atoms which then proceed to break down on their own. For this reason the term "induced radio-activity" is perhaps a more accurate description of what has been done. It is indeed probable that nature may have already produced such atoms for herself. Compared with the millions of years' history of radium, the radiation from radio-nitrogen "decays" to half its original strength in fourteen minutes. The corresponding figure for uranium, the first parent of radium, is 4500 million years, and that for radium itself 1580 years.

The Curie-Joliots' original discovery was announced at the end of January, 1934. In addition to radio-nitrogen, they had at the same time produced radio-phosphorus and radio-silicon, although it is important to realise that the necessary transmutations could in each case only be carried out on a minutely small scale. Subsequent progress has come from a rapid extension of the means by which artificial or induced radio-activity can be produced. In their first experiments the Curie-Joliots were dependent on a radio-active material as their source of energy. Less than two months later, Dr Cockcroft and Dr Walton of Cambridge, already famous in the world of science as the original large-scale atom-splitters, announced that

artificial radio-activity could be produced without resource to any radio-active material.

Instead of a stream of particles from polonium, Dr Cockcroft and Dr Walton used a stream of high-energy protons, or hydrogen nuclei. By bombarding carbon with these they found that they could produce the same radio-nitrogen which the Curie-Joliots had prepared from quite a different chemical element, boron. This was England's main contribution—that the whole process could be made strictly artificial, and that the same radio-elements could be produced by knocking different atoms about in different ways. In passing it may be mentioned that there are no less than five ways in which the unstable atoms of radio-aluminium can already be built up. In addition to their practical interest from the point of view of radio-activity, such experiments naturally throw considerable light on the constitution of the different atoms involved.

Another two months went by, and there came the announcement that Professor Enrico Fermi of Rome had prepared radio-active atoms by bombarding more than a score of different chemical elements with neutrons, yet another type of atomic particle. Finally, it was left to Professor E. O. Lawrence of California to try what at present appears to be the most promising method of all—bombardment with deutons, the nuclei of the newly discovered heavy hydrogen. It seems that radio-sodium can not only be made on an appreciable scale in this way, but that the radiation which it produces is definitely more powerful than that of radium.

Although three different types of radiation are produced by radium, the one in which doctors are chiefly interested is of the same kind as X-rays. The so-called "gamma rays" of radium are merely X-rays of shorter wave-length and greater penetrating power than any which man has yet produced. X-rays, however, provide a convenient standard by which the quality of nature's radiation can be judged. It so happens that the higher the electrical pressure applied to an X-ray tube, the shorter and more penetrating are the rays which it emits. An electrical pressure of a million volts is the highest which tubes have yet been built to withstand, although it is agreed that two million volt X-rays would be necessary to provide the medical equivalent of radium. The gamma rays of radium are, in fact, "two million volt X-rays", so that there is still a gap of a million volts to be bridged before X-rays can imitate completely the medical action of radium. It is quite possible that this gap may be bridged, through the direct medium of X-rays, in the relatively near future and at a reasonable cost. Yet if radio-sodium can be used practically, the scientist will be immediately three and a half million volts to the good. The "gamma rays" of radio-sodium are equivalent to 5·5 million volt X-rays, 3·5 million volts more powerful than those of radium, and 4·5 million volts more powerful than the most powerful X-rays which have yet been produced.

As to the scale on which operations are conducted, Professor Lawrence has already claimed that he can produce four hundred million radio-sodium atoms a second, and has expressed the hope that this output will soon be

increased more than a hundred-fold. Although this sounds a great deal, it is, in terms of weight, an almost incredibly small amount. Fortunately, however, the relatively short life of radio-sodium implies that, weight for weight, it is a much more intense source of radiation than radium. The figures so far published do not make a direct comparison easy, but it will probably not be far from the mark to suggest that when Professor Lawrence's hopes have been realised he will be able to supply neighbouring hospitals with amounts of radio-sodium equivalent to about ten milligrams of radium.

What would the advantages of radio-sodium be? In the first place there is the fact that many countries are not in a position to secure enough radium for their hospitals. Secondly there is the possibility, which cannot yet be decided, that radio-sodium may prove, when made under the most favourable conditions, to be an appreciably cheaper source of radio-activity. That this is a matter of some importance is shown by the fact that London's radium alone is valued at more than £250,000. On the other hand, it must be recognised that the further development of X-rays may, from this point of view, prove the best line of attack. Finally, and this is perhaps the most important point of all, the use of artificial radio-activity may have definite medical advantages.

Unlike radium, radio-sodium quickly finishes its work and, when it has done so, is harmless. It can therefore be left safely about the body without fear of dangerous after-effects. This means that it could be administered either in the form of an injection, or internally, or inserted in a

slowly dissolving capsule, none of which procedures are possible with radium itself. Moreover, with a considerable variety of radio-active materials in due course available, it should be possible to vary both the power and the quality of the radiation within wide limits. All these are possibilities, the value of which cannot be assessed without a prolonged series of experiments in many hospitals. For the present it can only be said that man's new power of producing radio-activity may well prove important.

No less remarkable is the case of wireless in which human engineers find themselves practically without competition from nature. It has been mentioned earlier that X-rays, ultra-violet rays, the waves of light and heat, and radio waves are all of the same kind. The only difference is in their wave-lengths, which increase progressively in the above order, and in the practical conditions necessary for their production. If the "gamma" rays of radium are counted as X-rays, and if it is accepted that X-rays are probably radiated by the hottest stars, then it may be said that nature makes use of practically the whole of this enormous range of wave-length. The only exception is provided by radio waves, of which nature's atmospherics are no more than a poor, if crudely powerful, imitation. As any radio listener knows, broadcast engineers pride themselves on exact control of wave-length, and in point of fact the whole range from 17 centimetres to more than 20,000 metres has been successfully utilised for human communications.

Nature's transmitter, the thunderstorm, is by contrast both wasteful and poorly controlled. A thunder cloud,

which is giving flashes at the rate of three a minute, is using up electrical energy more than a thousand times as fast as does Europe's most powerful broadcasting station, although fortunately for the world's listeners by far the greater part of the energy of every lightning flash is devoted to warming the air between cloud and earth. Moreover, although the primary wave-length of an atmospheric is in the neighbourhood of 300,000 metres, every listener knows that atmospherics are only too capable of interfering with any normal broadcast wave-length. Any human transmitter which distributed its energy over such a wide range of wave-lengths would soon be in trouble with the authorities. In fact it is necessary to go down as far in wave-length as about 10 metres to secure reasonable immunity from nature's unwanted transmissions. The electrical engineer's technique is unquestionably superior and, except in one doubtful instance, it appears that he has a monopoly of the new ultra-short and micro waves, which are already being used both in television and for short distance communication.

In other and curiously enough more homely fields nature may still be said to be winning. Perhaps the most outstanding examples are food production and the economical production of light. Not even the most optimistic devotee of the synthetic could claim that chemistry has so far been able to give a satisfactory imitation of nature's amazing power of building varied and elaborate foodstuffs from the simplest materials. All that the scientist has been able to do is to discover what appears to be the basic economy of the natural world and to learn, so to

speak, how to oil the works wherever he can get at them.

No fish or animal has, by itself, this power of food building. All other forms of life, including man, are ultimately dependent on the activities of either green plants or of analogous water-living organisms, called algae. The power of the plant is in its leaves. Every green leaf is coloured by one or more of four pigments, two of which are generally familiar as chlorophyll, with the aid of which the plant can absorb part of the energy of sunlight and use it to run its chemical factory. The same four pigments are found in algae, and it is known that nature's food factories are run on broadly similar lines, whether on land or sea.

The first and most vital stage of manufacture is the building up of sugars, and possibly also starches, from water and carbon dioxide, the waste gas which all animals breathe out. It is this stage for which the combination of green leaves and sunlight is essential. The all-important pigments, however, contain nitrogen in addition and so do proteins, which are also produced by plants and are the only type of foodstuff which can be used for body building whether in man or animals. Nitrogen is therefore the fourth great requirement of the plant factory and, in point of fact, represents one of the most important points at which human aid can be effective.

Although nitrogen, like carbon dioxide, is ready to hand in the atmosphere, plants have for some reason never developed the necessary power to turn it directly to account. This is left in part to thunderstorms, which

literally burn the air's nitrogen and wash it down to earth in more active form, and in part to the nitrogen bacteria of the soil. The most interesting of these are those that live as parasites in nodules attached to the roots of such plants as peas, beans and clover. Their job in the partnership is to breathe in nitrogen from the air, and to hand it in assimilable form to the plants to which they are attached. They at the same time enrich the soil's available supply of nitrogen for the benefit of other plants so that, although their mode of life is in a sense parasitic, it is also exceedingly useful. For the rest, the chemical diet of plants must also include phosphorus and sulphur, both of which are obtained under natural conditions from the soil.

Man, if he would increase his food supply, is still compelled, and likely long to be compelled, to work within nature's framework. Particular foodstuffs which the body only requires in small amounts, familiar as vitamins, he may be able to make artificially, and so ensure that in these items of diet he shall not go wanting. But for the main bulk of his food, whether as a source of energy or for body building, he remains dependent on nature. Proteins in particular are highly complex chemicals. It is almost inconceivable that it should ever be an economic proposition to build them up synthetically. Nor is the hope of tabloid food, if hope it can be called, any more securely grounded. The plain and unalterable fact is that the human machine must, like a motor-car, be supplied with a definite minimum of fuel if it is to remain even "ticking over", and appreciably more if it is to undertake active work. The bulk of a man's food ration

cannot therefore be indefinitely cut down—certainly not to the half-dozen tablets which some people seem to regard as the ultimate and ideal substitute for breakfast, lunch and dinner.

Measures for the increase of food production, which come within the range of practical politics, are therefore essentially limited. By dams and irrigation schemes generally any lack in water supply can be made good. The Assouan dam in Egypt, the Lloyd barrage in India and the Hoover dam in America are three of the great contributions made under this head by the English-speaking peoples. New varieties of plants can be bred which can be harvested within the shorter summer of the north, as has been done within living memory in Canada. At the same time disease-resisting varieties can be produced, like Sir Rowland Biffen's rustless wheat, which may effectively increase the average yield per acre which can be obtained. Finally, the activities of the nitrogen bacteria of the soil can be reinforced in one of two ways. Either chemists can abstract nitrogen from the air and turn it over to farmers in a form which their crops can absorb; or if the area of a leguminous plant is to be extended, its accompanying bacteria can be directly introduced along with it. This has been necessary in the recent extension of the soya bean, first from Japan to America, and then from America to England. In each case bacteriologists had to breed the appropriate strain of bacteria in their laboratories, so that the plants would not go short of nitrogen in their new homes.

Similarly, by animal breeding experiments it should be

possible to increase still further the cow's capacity for milk production, and that of the hen for producing eggs. It should also be possible to reduce the very heavy toll which disease levies on any form of livestock farming; and, by scientific feeding, to secure a more economic transfer of vegetable into animal food. Much has already been done, and more will no doubt be done. According to one famous prophecy, made before both the northern extension of the wheat limit and the development of artificial fertilisers, the world should by now be suffering from an acute wheat famine instead of an obstinate world surplus. According to a more recent and more cautious estimate, the earth's limits of food production in relation to its increasing population will be reached in about two hundred years' time. It may, of course, be so, but there seems to be no reason to believe that the one prophecy will be fulfilled rather than the other.

In any case, while progress is confined to such lines as have already been indicated, it will have to be admitted that the victory is still with nature. There is an old-fashioned dictum that the business of the state is to "hinder the hindrances" to individual happiness. The part played by science in food production may be not inaptly described by the same phrase. Nature's methods are retained while at the same time every possible difficulty is removed from her path. Even in the production of artificial fertilisers, it may be remarked, the manufacturing scientist is but following in nature's steps. One method by which nitrogen is captured from the air follows, more or less exactly, the technique of the lightning flash. In the other,

the nitrogen is captured in the same form that it is naturally released from decaying vegetation or animal refuse, that is, ammonia.

A second example of the victory of nature has already been mentioned—that of the economical production of light. It may, however, be a surprise that the model of efficiency in this direction is not the sun, but the firefly or glow-worm. As everyone knows, the sun radiates heat and ultra-violet rays as well as light and, regarded merely as a light producer, it is only one-sixth efficient. The glow-worm's radiation, on the other hand, consists practically entirely of light, so that it may be said to produce "cold" light.

The sun's weakness as a light producer, which is shared by all normal forms of man-made lamp, is that it only radiates because it is hot. As has already been mentioned in connection with star temperatures, the radiation emitted by all solid bodies is essentially varied in character, although the wave-length distribution depends on the temperature of the radiating surface. From this point of view the sun, with a radiating temperature of 6000 degrees, is as efficient a radiator of "hot" light as it could be, although it would probably be more accurate to say instead that our eyes have been adapted in the course of evolution to make the best possible use of the radiation provided. The sun in fact has set the wave-length standard for all forms of lighting. There are other stars which radiate, on the one hand principally heat waves, and on the other principally ultra-violet rays; and, no doubt, if we had happened to live on one of their satellites, assuming

they have any, our eyes would have been adapted to see those types of radiation instead of the waves we are pleased to call light—merely because we can see them.

Any normal electric lamp works on the same principle as the sun. It radiates because its filament is hot although, for obvious reasons, electrical engineers cannot be expected to operate their lamps at the sun's ideal temperature. Similarly, every advance in electric lighting up to quite recent years has taken the form of a further increase in the filament temperature. The element tungsten can be made hotter than carbon. Tungsten filament lamps were therefore an improvement on the older carbon variety. They were, in fact, about three times as efficient. Then came the discovery that the filament of a gas-filled lamp could be heated even more strongly, and with it a further increase in efficiency of rather more than 50 per cent. But even so electric lamps were little more than 10 per cent. efficient, though this was sufficiently near to the one-sixth efficiency of the sun to make it appear that, along these lines, the limits of progress had very nearly been reached.

Heat, however, is not the only possible source of light. The production of light, and for that matter of all other kinds of radiation, is due, in the last analysis, to a complicated dance executed by electrons; and there are other ways of stimulating electrons to execute such a dance than by heating them. One is by passing an electric current through a gas under low pressure. This is the latest method adopted by illumination engineers. The other is by the stimulus of chemical change—which is the way the firefly produces its light.

There is nothing new about the gas-discharge method as such. Luminous tubes of this kind had been known as laboratory toys for more than a hundred years before the first incandescent lamp was constructed, and for many years they have been used on a large scale for publicity purposes. The difficulty was to find a gas-discharge lamp which would give a white, or nearly white, light. The red light of the neon sign is inevitably unsuited by its colour for any normal illumination. The yellow sodium lamp appeared more promising but, although it represented a further two and a half times gain in efficiency, its light was all of one colour, its efficiency short-lived and the necessary supply circuits complicated.

Another possibility was the mercury discharge tube which, under normal conditions, produces light of an unpleasant blue colour. It had, however, been known since 1906 that a colour much more nearly approaching white could be produced if the mercury vapour was used in rather higher concentration and the gas operated at a correspondingly higher temperature. This is the secret of the new gas-discharge lamps which have recently been introduced for street and industrial lighting. The new lamps are roughly twice as efficient light producers as the sun, more than two and a half times as efficient as the best filament lamps, and about eighteen times as efficient as the original carbon filament lamps. Their colour, it must be admitted, is somewhat on the blue side of white, but not sufficiently so to be objectionable for many purposes, particularly street lighting.

What will be the future of these lamps? Probably it is

safe to prophesy that a practical lamp will in due course be produced which will make a still nearer approach to the white standard of sunlight. It is also reasonable to suppose that gas-discharge lamps will ultimately become general for street lighting, as also in many departments of factories and other large industrial buildings. On the other hand, it will probably be much longer, if at all, before lamps of this kind become available for domestic use.

If it were not for the glow-worm, electrical engineers would be able to claim that they had beaten nature. Unfortunately, while the gas-discharge lamp is about twice as efficient as the sun, the glow-worm is probably about three times as efficient as the gas-discharge lamp. It is, in fact, nearly perfectly efficient, concentrating practically the whole of its radiation into the range of visible light. This applies equally to the true fireflies of tropical America, which the natives use in many parts as lamps, keeping them in cages, and to the less vivid glow-worm of England. All these light-giving beetles, for that is what they are, have the power of producing "cold" light, so that virtually none of the available energy is wasted as heat. There seems no doubt that the necessary energy is provided by some slow process of chemical change. This is also the origin of the light emitted by slow-burning phosphorus, and probably also of the many coloured lights which Dr William Beebe has reported are carried by various deep-water fish.

Quite recently, laboratory scientists have published a recipe for the production of "cold" light by a succession

of chemical changes. In this sense it is true that the firefly's skill has been imitated. But the triumph is of academic interest only. Unfortunately the apparatus used is quite unsuited for continuous light production under practical conditions, and the cost of the necessary chemicals would alone be sufficient to justify a charge of five pounds per firefly light per hour. The firefly, on the other hand, is in the happy position of making its own chemicals, without either conscious effort or the need for any form of expenditure. If, therefore, man were determined to use this most perfect method of light production, he would still find it cheaper to follow the natives' example and use genuine fireflies. Science has made great strides in this matter of illumination, but once again the last laugh is with nature.

Taking a wider view, it appears that in any true summary of the position the balance must be delicately held. We must even be prepared to admit that the comparison which we are trying to make may have little real meaning—if we look too closely at either nature or science. Yet regarded as a rough and ready form of stocktaking, it may be claimed that the attempt is wholesome. One of the difficulties is that the presumed competitors seldom meet on fair ground. Electricity, for example, has two main uses—as a means of conveying power from one place to another, and as a signalling or control system. Nature has no interest in dynamos or high-tension cables, for all her self-acting organisms are directly driven by the energy released on the spot in chemical changes, e.g. in muscles. Looking only at this department it would

therefore appear that science had far outstripped nature. Yet, if we turn instead to electric signalling and control, then we find that the nerve system and particularly the brain represent such a delicate and complex network as no human engineer could hope to emulate.

Again, although the whole of chemical science may be said to be based on nature's principles, it has developed along quite different lines. Nature, for a start, seems to have no interest in turning out pure chemicals. It has found it simpler so to develop its organisms that they can make use of chemicals prepared in impure form. From this point of view nature is, by human standards, a bad chemist. Yet, as has already been indicated, many of the chemicals of which living matter makes use are far too complex in structure for any scientist to be able to make them for himself.

Similar contrasts can be elaborated almost indefinitely. No bird could hope to compete with an aeroplane in mere speed, yet in versatility of movement and in immunity from accident the bird undoubtedly wins. So also it may be supposed that nature has no interest in the more elaborate types of calculation which, in the modern world, are most satisfactorily entrusted to calculating machines. In so far as weeks of brain work can be compressed into a few minutes wheel-turning the victory is with the scientist. But when it comes to the sort of calculation which nature recognises to be necessary, then it does the job with all the accuracy which is needed and at very much greater speed. The judgment of distance by man's two eyes is in principle the equivalent of one of the standard opera-

tions of trigonometrical surveying. To follow the flight of a tennis ball with two such instruments, and to meet the ball with a racket, also moving, would, from a mathematician's point of view, involve a whole series of highly elaborate calculations. Yet even a beginner at tennis manages somehow to establish contact with fair frequency, and probably entirely fails to realise that his brain has had anything to do with his success.

Finally we may notice that nature is far too wealthy to have any interest in economy for its own sake. Evolution is to a large extent the record of wasteful and unsuccessful experiment. The American oyster may discharge more than five hundred million eggs during a single season, of which all but a minute proportion perish before maturity. Similarly, if we are so conceited as to imagine that the production of a family of planets is the object of a star's existence, then the proportion of stars which fulfil their purpose may well be equally small. Even the all-important process of food production, as carried on by plants, is not particularly efficient, for in the case of cereals and potatoes only between 2 and 3 per cent. of the sun's energy is successfully utilised. Any comparison between the achievements of man and nature which takes economy as a criterion must therefore be received with caution. Man seldom remains for long in the position that he has no need to husband his resources.

In general, although the scientist takes his ideas from nature, the uses to which he directs them are widely divergent. Thus it is that the successes of science, regarded as a material competitor of nature, tend to be most striking in

those directions which are not essential to the normal requirements of life. The examples of artificial radio-activity and the controlled production of radio waves may again be instanced. Similarly, the whole of the many triumphs of modern medicine may be placed in the same category, on the ground that the preservation of the unfit is no part of nature's plan. In other cases, in which man appears to be in direct competition with nature, there are already indications that progress is being made. Two possibilities which at once suggest themselves are the deliberate creation of new species and the control of human evolution. It would be a bold critic who would attempt to set limits to the potential powers of organised science. There can be no doubt that a similar balance sheet, presented fifty or a hundred years hence, will make very different reading.

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